Elwha River Restoration Project
Draft
Sediment Management and Monitoring Plan

Based on Recommendations of the Elwha River
Physical Processes Monitoring Workshop
Port Angeles, Washington
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Note to Reader:

This plan provides technical recommendations on monitoring of sediment impacts as a result of dam removal activities on the Elwha River. The Elwha River Restoration Project presently has a budget of about $1.8 million to pay for monitoring activities. Complete funding for all the monitoring recommendations listed in this plan has not yet been obtained.

ACKNOWLEDGEMENTS

The sediment management plan compiled in this report is based on feedback from a workshop held during August 13 to 17, 2001 in Port Angeles, Washington. During this workshop, a small group of technical specialists visited critical sites along the Elwha River, and then participated in workgroup sessions designed to generate ideas on what types of monitoring could be done in order to: (1) provide information in a real-time environment that will assist project management in decisions regarding the actual removal of the two dams, and (2) provide valuable information on a longer-term scale that will both identify and quantify physical processes associated with ecosystem restoration following dam removal. The group also provided ideas on the locations, frequencies, and duration of monitoring that could be accomplished, along with ideas on several types of new technology that could be incorporated into the monitoring program. Feedback from this technical group of specialists played a vital role in the formation of the contents of this report. We will like to thank all of the participants and reviewers for their time and participation at the workshop, and hope they will all remain active participants as the project progresses in the future.

Field Trip to Glines Canyon Dam, WA

Meeting in Port Angeles, WA

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EXECUTIVE SUMMARY

Background

The removal of Elwha and Glines Canyon Dams has been proposed to fully restore the Elwha River ecosystem and native anadromous fisheries in a safe, environmentally sound, and cost-effective manner. The river erosion alternative was selected by the Secretary of the Interior as the plan to manage the nearly 18 million yds^3 of reservoir sediment trapped behind the two dams (Olympic National Park, 1996 and U.S. Department of the Interior, 1997). This sediment management plan will allow the Elwha River to erode and transport a portion of the reservoir sediments downstream by natural processes (generally without hydraulic or mechanical dredging). Depending on river flows, it is predicted that about one-quarter to one-third of the coarse sediment (sand and gravel) and about one-half to two-thirds of the fine sediment (silt and clay) will be eroded and transported downstream from the two reservoirs as a result of dam removal. The balance of the reservoir sediments is predicted to re-vegetate and remain stable over the long term in terraces along the former reservoir margins. The river erosion alternative requires mitigation for expected impacts to water quality from the release of fine (silt- and clay-sized) sediments carried in suspension, and for potential impacts to downstream flood stages and river channel migration from the deposition of coarse (sand-, gravel- and cobble-sized) sediments on the river bed. Environmental and cultural issues will also be addressed by planning work shutdowns during fish migration periods (fish windows), restoring the sacred sites at Elwha Dam to near pre-dam conditions, and retaining certain structures at Glines Canyon Dam for historic preservation and public interpretation.

Sediment Monitoring Plan Objective

The objective of the Elwha River Restoration Sediment Monitoring Plan is to identify the critical monitoring parameters needed to evaluate the changes in physical river processes and characteristics both during and following the removal of the two dams on the Elwha River. The plan deals with the river's hydrologic, hydraulic and morphologic characteristics, sedimentation processes, interactions among flow and sediment transport, and aquifer responses. The sediment monitoring plan does not cover detailed biological, vegetation, or near shore (coastal) responses to dam removal activities. Separate workshops focusing on biological and coastal responses to dam removal have occurred and monitoring plans are expected to be generated. Information from sediment monitoring plan activities will be available for other monitoring groups to utilize.

Adaptive Management Monitoring Versus Restoration Monitoring

For purposes of this plan, adaptive management monitoring is used to describe monitoring tasks that are necessary to accomplish dam removal. Restoration monitoring is used to describe additional monitoring tasks that would provide information necessary to scientifically document the role of physical processes in the natural response of a fluvial system to dam removal. There is currently only funding for adaptive management monitoring activities, and, therefore, the most detail and emphasis are placed in this plan on adaptive management tasks. However, restoration monitoring ideas are presented in this plan in the hope that interested parties will pursue funding options for these learning opportunities. The adaptive management sediment monitoring activities are limited to tasks necessary to ensure the following resource management objectives are accomplished:

- Sediment concentrations should not overwhelm the water treatment facilities or municipal and industrial wells or significantly reduce water yield of those wells
- Sediment concentrations should not be high enough that they prevent fish from migrating into or out of the Elwha River during critical migration periods (fish windows)
- Sediment deposition along the riverbed should not increase flood stage beyond the design limits of new flood protection infrastructure (constructed prior to start of dam removal)
- Sediment deposition along the riverbed and flood plain should not increase the water table to a level that significantly reduces property value

- Future channel processes should not additionally harm existing infrastructure and property beyond impacts associated with historic or existing processes
- Dam removal should be accomplished in a safe, controlled manner that prevents large landslides from entering the reservoir or inducing a flood wave into the downstream river channel

Adaptive management monitoring is intended to be highly operational and conducted in "real time." Information developed as part of adaptive management monitoring will feed back directly to project managers and be used to verify or modify dam removal scheduling, and to trigger contingency actions required to protect downstream water quality, property, and infrastructure. Adaptive management monitoring would cease when the sediment impacts from dam removal are no longer detectable in the downstream river channels relative to the re-established natural sediment supply. Based on sediment studies conducted for the EIS, high sediment loads in the downstream river channel are expected to continue for up to 3 years following the completion of dam removal depending on the occurrence of floods both during and immediately following dam removal (Randle et al, 1996). On the other hand, restoration monitoring would not need to be conducted on a real time basis. Restoration monitoring could be either short term occurring at the same time as collection of adaptive management monitoring data, or could continue much longer than 3 years following dam removal to document longer term changes in the system. Information from restoration monitoring activities would be used to measure project performance, would result in a body of scientific knowledge applicable to both understanding and interpreting natural river restoration and healing, and would be applicable to the design of future river restoration projects in other locations. In many cases, information from adaptive management monitoring could provide baseline data and be integrated with restoration monitoring results.

Adaptive Management Responses to Dam Removal

Certain sedimentation processes and conditions may be undesirable in the short term and require mitigation during dam removal. Other processes are expected to occur over longer time frames and will be part of the natural evolution of the fluvial system to a new state of dynamic equilibrium. Some management of these processes may be necessary, or desirable, during the years following dam removal, however, the need for intensive intervention to manage physical processes is not anticipated.

Adaptive management responses as a result of sedimentation processes will be triggered by feedback from real-time monitoring tasks and could include several options:

- Accept the impact and proceed with dam removal and reservoir drawdown.
- Modify monitoring methods, locations, or frequencies.
- Modify water treatment techniques.
- Take remedial actions to locally protect downstream infrastructure, wells, and property.
- Alter the rate of dam removal and reservoir drawdown.
- Temporarily halt dam removal and reservoir drawdown.

Monitoring Categories

Monitoring categories and their applicability to the adaptive management and restoration programs are listed in the following table.

Monitoring Category	Adaptive Management	Restoration
Reservoir Sediment Erosion and Redistribution ➢ Delta erosion and downstream progression ➢ Release of coarse sediments from the reservoirs ➢ Re-establishment of reservoir flood plain and vegetation	X	X
River and Reservoir Hillslope Stability	X	X
Water Quality (Suspended Sediment Concentration & Turbidity)	X	X
Riverbed Aggradation and Flood Stage ➢ Bed material size measurements ➢ River water surface elevations ➢ Channel geometry	X	X
Aquifer Characteristics ➢ Water table elevations ➢ Well water yields, quality	X	X
River Channel Planform and Channel Geometry	X	X
Large Woody Debris Processes	X	X
Coastal Processes		X
Sediment Budgets (Bedload Measurements, Channel Storage Changes, Comprehensive Channel Survey)		X

Timing of Adaptive Management Monitoring Tasks

The timing and frequency of adaptive management monitoring tasks vary depending on the stage of dam removal. Some tasks must be accomplished prior to the start of dam removal, some during the reservoir drawdown, and others will not be initiated until the reservoir pool is essentially gone. The frequency of monitoring depends on the progression of sediment transport both in the reservoirs and in the downstream river channel. Additionally, during certain time periods dam removal activities will be temporarily halted and the frequency of some monitoring activities may be slowed or even delayed until dam removal is resumed. Dam removal will be temporarily halted when high flows result in overtopping of the dam resulting in unsafe working conditions. Dam removal will also be temporarily halted during fish windows. Fish windows are time periods established by fishery scientists during which adult fish may be migrating into the river channel for spawning or for juvenile fish to migrate back to sea and it would be ideal to have low levels of turbidity in the water. Certain monitoring activities such as stream gaging would continue during floods to help provide information for management decisions related to protection of downstream infrastructure, property, and residents.

Several monitoring activities will be accomplished prior to dam removal to generate a set of baseline data that will help scientists better understand the role of dam removal in changing sediment processes both during and after dam removal. In addition, collecting data prior to dam removal will allow new field data collection techniques to be explored and methods to be firmly established in a controlled setting rather than during the dam removal when the river will be much more dynamic.

The timing and frequency for monitoring tasks accomplished during dam removal will depend on the stage of dam removal, results from other monitoring tasks, and the progression of sediment processes associated with dam removal. For instance, during the initial reservoir drawdown monitoring activities will focus on river erosion through the upstream deltas and the downstream progression of delta sediments. As long as a reservoir pool remains during dam removal, eroded delta sediments will re-deposit as a new delta within the receding reservoir.
During this period the monitoring frequency will be either continuous (real-time data collection such as gage sites) or once per drawdown increment for activities that are highly dependent on the progression of dam removal.

After the top half to two-thirds of the dam has been removed, the eroding delta sediments will be of sufficient volume to reach the dam and the reservoir pool will become completely filled in with sediment (Randle et al., 1996). At this critical point in time, further dam removal will result in the downstream release of coarse sediments. At this point, certain monitoring activities will occur on a one-time basis to assess the volume of sediment in the remaining reservoir pool and the stability of the exposed sediment in the former reservoir area. The results from these activities will help determine if the exposed sediments in the upstream reservoir are stable or if continuing dam removal could result in uncontrolled releases of sediment that exceed predicted levels. This will be an important stage of monitoring because uncontrolled sediment releases in excess of predicted levels could cause unanticipated flooding and water quality problems to occur.

Once dam removal is resumed, the coarse sediments released from the former reservoir area will become subject to deposition along the downstream river channel, including locations such as pools, backwater channels, eddies (recirculation zones), and flood plain edges along the river channel. At this stage in dam removal monitoring activities would be initiated that track the downstream progression of coarse sediments. The frequency of these tasks will depend on the speed of the sediment wave once it is released from the reservoir.

For this monitoring plan, the completion of dam removal is defined by when the last bottom portion of each dam has been removed. Within three to five years following the completion of dam removal, sediment impacts associated with dam removal are predicted to decrease to minimal levels. However, as long as significant sediment impacts still exist adaptive management activities such as operation of the water treatment plant and potential mitigation associated with unanticipated flooding or bank erosion will continue. In order to determine when sediment impacts downstream of the dams have decreased to negligible levels, certain monitoring activities will continue after dam removal is completed. It is planned to have these monitoring activities continue for three years following dam removal, but if unanticipated sediment impacts are still occurring monitoring would need to continue until the impacts can be deemed non-critical to water quality, flooding, or other safety issues that would require adaptive management actions. Non-critical is defined such that sediment levels have returned to natural levels defined by the incoming load upstream of the dams. If sediment stored in the reservoir areas are still being actively reworked and transported into the downstream river channels, then sediment levels may still require some additional monitoring.

Criteria to determine when to stop adaptive management monitoring activities were developed based on when the erosion of reservoir sediments has essentially stopped or slowed to levels such that suspended sediment concentrations and turbidities have reached natural conditions in the Elwha River downstream from the former dams (see Appendix B for further details). "Natural levels" are defined as equivalent to what they would be had the dams not been in place, and will be determined based on levels in the upstream, undisturbed watershed (above Lake Mills). A determination that natural conditions have been achieved for suspended sediment concentration and turbidity would be based on achieving the following three conditions:

- Condition 1: Stable Relationship between Upstream and Downstream Suspended Sediment Concentrations or Turbidities based on a comparison of weekly averages above a threshold, weekly maximum values, or weekly sediment loads.
- Condition 2: No Significant Change in Reservoir Sediment Volume. Condition 2 would be met when the net erosion of reservoir sediments since the last semi-annual measurement in the former Lake Mills and Aldwell is insignificant (less than 5 percent) relative to the long-term average annual sediment load of the Elwha River.
- Condition 3: Hydrologic and Geomorphic Evidence of Stabilized Reservoir Sediments. Condition 3 would be met when the remaining reservoir sediment terrace banks are determined to have attained a level of geomorphic stability comparable to the reference reach at Krause Bottom (Geyser Valley).

Adaptive Management Monitoring Prior to Dam Removal

The adaptive management monitoring tasks that will be required prior to dam removal to establish baseline (existing) conditions for the project are:

<u>Prepare a more detailed implementation plan</u> for the adaptive management monitoring plan provided in this document. This plan will be developed by the ONP geomorphologist assigned to the Elwha project with assistance from Reclamation's Sedimentation and River Hydraulics Group and the National Park Service Water Resources

Division. The implementation strategy would address adaptive management monitoring tasks and dissemination of this information.

Hire and train any necessary staff to implement the adaptive management monitoring. Some monitoring crews may be hired as on-site project staff. Other crews may be comprised of technical staff within the Department of the Interior and the Lower Elwha Klallam Tribe. Contracts for technical support from Universities and consultants may also be considered.

Conduct a bathymetric survey of lake mills to define initial volume of reservoir sediment prior to the start of reservoir drawdown. The last estimate of the volume of reservoir sediment present in Lake Mills was made in 1994.

Install stream gages to measure river stage, discharge, temperature, turbidity, and suspended sediment concentration along the following river locations:

- Upstream from Lake Mills – A gage was established at the entrance to Rica Canyon at Goblins Gate (RM 17.5) in 2003 but was blown out during a flood in that same year. As a result, a new gage (USGS 12044900) was installed in 2004 at an alternate location at the upper end of Lake Mills below Rica Canyon and above Hurricane and Cat Creeks. This gage presently measures stage and turbidity, and will also be used to measure discharge and suspended sediment concentrations closer to the start of dam removal. The location of this gage may need to be adjusted as the reservoir is drawn down during dam removal.
- Between the Two Reservoirs - A long-term discharge gage already exists near McDonald Bridge at RM 8.7 (USGS 12045500); new instruments have been installed to measure temperature and turbidity, and closer to the start of dam removal suspended sediment concentration will also be measured.
- Downstream from Elwha Dam – Presently turbidity and temperature is measured at the existing intake location for the City of Port Angeles water diversion. Because the diversion facilities will be replaced prior to dam removal, a new gage will be installed prior to the start of dam removal between the mouth of the canyon (RM 4.3) and the single-lane bridge on Elwha River Road (RM 3.2); discharge, suspended sediment and turbidity measurements will be made at the new gage.

Measure and document initial conditions at 22 river cross sections where riverbed aggradation and flood stage are to be monitored (see Table 5 in main report and aerial photography in Appendix A for locations).

- Establish and survey monuments and bank erosion pins at river cross sections.
- Define river cross section topography from the 2001 LIDAR data of the floodplain and new channel cross section survey data (see section 2.10).
- Establish and survey staff gages at all monitoring cross sections and continuous stage recorders at 6 cross section locations (locations described in Table 5 of main report).
- Compute and then measure the stage-discharge relationships at all monitoring cross sections. The HEC-RAS hydraulic model has already been applied to the Elwha River based on 2001 survey data (U.S. Army Corps of Engineers, report in progress). This model will be used to compute the stage-discharge relationships at all monitoring cross sections for river flows up to the 100-year flood. River stage will be measured at these cross sections (for a range of flows during the winter flood season) and associated with the discharge measurements from the nearest stream gage to verify, and possibly adjust, the computed stage-discharge relationships.
- Determine the initial bed-material size gradation at each river cross section prior to reservoir drawdown and dam removal. The bed-material size gradations were measured in 1994 by Gilbert and Link (Reclamation, 1996). These size gradations may not have significantly changed at most locations because the riverbed is generally thought to be armored. A field trip will be conducted to document the bed-material at the monitoring cross sections by photographs and visual inspection.
- Document (including photographs) any active bank erosion and the presence of log jams along the river channel.

Photograph all potential reservoir landslide areas that have been reported by Burt (2003) to document initial conditions immediately prior to dam removal. Existing reservoir landside areas include a large landslide on the left side of Lake Mills near the upstream end, three small landslides along the left side of Lake Mills near the downstream end of the reservoir, and seven areas along Lake Aldwell of which four are very small in size (Burt, 2003). The locations of these potential landslide areas are documented by Burt (2003).

Photograph any potential landslide areas adjacent to the river channel to document initial conditions immediately prior to dam removal. Existing landslide areas adjacent to the river channel include the right bank downstream from the Olympic National Park Historic Ranger District buildings and a large area along the left side of the river near the mouth of the Elwha River.

Install WEB cameras overlooking Lake Mills, Glines Canyon Dam, Lake Aldwell, and Elwha Dam to begin monitoring of dam removal activities.

Install equipment to monitor water levels and well yield in wells that have been identified as potentially at risk from dam removal impacts along the river corridor. Installation of water level measurement devices in monitoring wells near wells of interest would occur at least 3 months prior to dam removal to collect some baseline data. One measurement of well yield at each well of interest would be done within one year prior to dam removal.

Adaptive Management Monitoring during Reservoir Drawdown and Dam Removal

The adaptive management monitoring tasks that will be performed during reservoir drawdown and dam removal are summarized in the list below. These activities will help monitor the sediment impacts associated with dam removal. If the impacts or the rate of impacts are greater than predicted (based on previously documented numerical and physical modeling), adaptive management responses would be generated as described in Section 3 and 4 of this report.

Continuously monitor the river flow, temperature, turbidity, and suspended sediment concentration, during reservoir drawdowns and continuing until the dams are removed. Measurement of river flow will help estimate sediment erosion and transport rates. Measurement of temperature, turbidity and suspended sediment will be used to monitor the impact of dam removal on water quality and guide water treatment operations. If water treatment operations cannot keep pace with the sediment impacts associated with dam removal, the rate of dam removal and associated release of suspended sediments would need to be slowed or halted, or water treatment techniques would need to be altered to ensure water treatment operations could continue.

Monitor the reservoir sediment erosion and redistribution in Lake Mills and Lake Aldwell while the reservoir pool remains with WEB cameras and following activities. Delta sediments must be eroded and redistributed in such a way that large portions of the remaining reservoir sediment can not unexpectedly be transported into the downstream river channel and cause unanticipated flooding or water quality issues. If the rate of sediment erosion and redistribution does not reasonably match predicted conditions generated from numerical and physical modeling, the rate of dam removal may need to be increased or slowed down or manual reworking of sediments may need to occur to achieve the desired reworking of delta sediments. Monitoring of the reservoir sediment will consist of GPS measurements of the advancing delta front and the longitudinal slope of the main river-erosion channel in each reservoir. The percentage of sediments eroded from the exposed delta (above the reservoir elevation) will be estimated at least once per reservoir drawdown increment. In addition, the reservoir WEB cameras will also be monitored during and after reservoir drawdown and dam removal.

Inspect potential landslide areas along Lake Mills and Lake Aldwell at least once per drawdown increment at the same time the delta is being surveyed by boat. Also, inspect the potential landside area along the Elwha River downstream from the Historic Ranger District buildings at the same time cross-sections are being monitored after coarse sediment has been released from the reservoirs. If an unexpected landslide occurred along the reservoir pool, dam removal would have to be halted until the potential for additional landslides could be assessed. If landslides should occur along the Elwha River and affect critical infrastructure, such as the Park road, then the infrastructure would have to be repaired.

Conduct a survey of the reservoir bottom within the remaining reservoir pool, the river erosion channel, and of the exposed reservoir sediment once each reservoir reaches the critical elevation (485 ft for Lake Mills and 140 ft for Lake Aldwell). After the dam is removed beyond the critical elevation, the rate at which delta sediment is released to the downstream river channel is dependent on the rate of dam removal and the river discharge. The new survey data of the reservoir sediment volume will be compared to the initial conditions survey data in each reservoir to determine the volume of reservoir sediment that has re-deposited in the remaining reservoir pool and the volume of sediment that has not eroded above the receded reservoir pool. If the redistribution of reservoir sediment has not kept pace with predicted rates, dam removal would need to be halted until the sediment is redistributed as predicted. Manual efforts such as creating a pilot channel to encourage sediment reworking and redistribution could be considered as an alternative to waiting for higher river flows to rework exposed sediment.

Monitor the width, longitudinal slope, and bank or terrace height of the main river-erosion channels within the two reservoirs once per dam removal increment after the reservoir deltas have reached the dams. Inventory banks along the main (active) river channel for evidence of existing erosion by the river. Inventory would be made using digital photographs and possibly video with corresponding notes documented by a licensed engineer or geologist. This inventory would occur during the first longitudinal profile survey during the first year of dam removal and prior to coarse sediments being released from the reservoirs.

Monitor the downstream progression of the first bedload wave by sampling for sand and gravel-size bed material at identified cross sections (see Table 5 in main report) after Lake Mills' delta has reached the dam. It is not known how fast the sediment wave will move, but monitoring will continue until the first bedload wave from Lake Mills reaches the mouth of the Elwha River. The location of the bedload wave will be used to determine when river stage and channel geometry monitoring will begin at a particular cross section (see next paragraph). If the bedload wave cannot be tracked after release of coarse sediment from reservoirs, cross-section monitoring would begin at all sections during the next spring or fall low-flow period.

Periodically monitor the river stage and channel geometry after the first bedload wave has reached a monitoring cross section. The channel geometry of these cross sections and a continuous longitudinal river profile will be resurveyed at least once per year. In addition to the manual staff gage readings, river stage will be continuously monitored at six key cross sections and reported on the WEB.

Monitor the presence of large woody debris and bank erosion at critical infrastructure locations that may be at risk to localized flooding due to large woody debris deposited during dam removal to provide early detection of problems. Monitoring of large woody debris would occur during river stage measurements at identified cross sections (see Table 5 in main report). Baseline data would be collected at these cross section locations prior to dam removal when the river stage equipment is installed at each cross section.

Monitor water levels in wells along the river corridor on a monthly basis during reservoir drawdown and dam removal. In addition, well yield and water quality will be continuously monitored at all municipal wells.

Adaptive Management Monitoring after Dam Removal Is Completed

Certain monitoring activities will continue until it is determined that sediment impacts related to dam removal have been reduced to natural levels, such that no adaptive management actions would be required. The determination of when natural suspended sediment concentrations and turbidities are achieved, downstream from the dams, would be based on the results of monitoring data from river flow (upstream and downstream from the dams), monitoring data from the former reservoir areas, and from the results of a terrace bank stability assessment of the former reservoir areas (see Attachment B for more details). The return to natural sediment levels is estimated to occur within three years following completion of the removal of the dams.

After dam removal, the width, longitudinal slope, and bank or terrace height of the main-erosion channels in the former reservoir areas would be monitored once per quarter for an additional three years. River stage and channel geometry downstream of Glines Canyon Dam will also be continually monitored for three years to detect any unanticipated flood potential and mitigate with flood protection measures if necessary.

Continuously monitor the river flow, temperature, turbidity, and suspended sediment concentration with gages for three years after dam removal is completed to provide information needed to determine when the sediment impacts from dam removal have finished. Continuously monitor reservoir area with WEB cameras for three years.

Proposed Restoration Monitoring

Several monitoring topics were proposed at the 2001 workshop that fall in the category of restoration monitoring. Additional research ideas were further developed at a second workshop devoted to research topics associated with the Elwha Dam Removal project in February 2005. Answers to these research topics will provide a valuable set of information and analysis that could be used to measure overall project performance and provide a body of scientific knowledge. Many restoration monitoring tasks would begin prior to dam removal and continue until at least the remaining reservoir sediments have become stabilized as identified in the criteria for stopping adaptive management monitoring activities (see Appendix B). However, the long-term channel and flood-plain response to dam removal depends on the natural upstream sediment supply. A few decades may be required for the river channel and flood plains to reach a dynamic equilibrium and some restoration monitoring activities could potentially be extended for a longer time period. Restoration monitoring could be implemented by a variety of approaches that will emphasize partnerships between participating agencies, other interested parties, and academic institutions. Many of the proposed restoration monitoring tasks are an expansion of adaptive management monitoring tasks in order to provide more detail and frequency of data collection. For this reason, in many cases the restoration monitoring tasks could be accomplished by the same individuals or agencies performing adaptive management monitoring providing some potential cost saving measures.

Monitoring Plan Cost Estimates

Approximately 1.8 million dollars of project funding is currently available to support the adaptive management monitoring tasks. Budget estimates for adaptive management monitoring activities have been developed by the Bureau of Reclamation and the United States Geological Survey and are available as a separate document. The initial cost estimate for the adaptive management monitoring tasks is between 2 to 4 million dollars, depending on the frequency and number of stream gaging activities. The cost estimates may need to be adjusted as new technologies become available or if new management questions should arise.

No project funding is currently available for restoration monitoring, but other research funding sources might be available to support these activities. The restoration monitoring program will provide valuable information on the rate that the river system approaches a dynamic equilibrium. In addition, restoration monitoring will provide information that will be particularly valuable to other restoration projects involving dam removal. A restoration monitoring program could easily cost as much as the adaptive management program. Although detailed cost estimates are not provided in this report, concepts for research ideas are presented that could be expanded into funding proposals by interested parties.

1.0 INTRODUCTION

1.1 Background

The Elwha River flows northward from the Olympic Mountains of northwest Washington State to the Strait of Juan de Fuca near the town of Port Angeles, Washington. The river system includes over 100 miles of tributary streams and drains a watershed area of 325 mi^2, 83 percent of which lies within the boundaries of the Olympic National Park (see Figure 1). With a mean annual flow of 1,508 ft^3/s, and a mean annual runoff of 76 in, the Elwha River is the fourth largest river on the Olympic Peninsula. The highest peak flow recorded was 41,600 ft^3/s on November 18, 1897 and the lowest mean-daily flow recorded was 10 ft^3/s on October 3, 1938 (both measurements recorded at USGS McDonald Bridge Gage located between Elwha and Glines Canyon Dam at river mile 8.7).

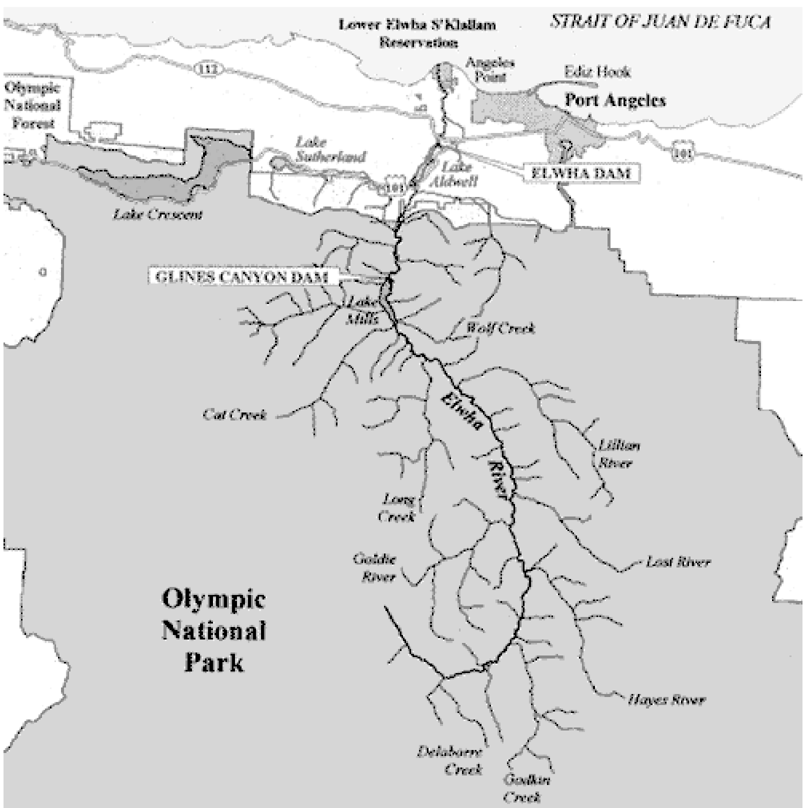

Figure 1. Project Location Map

Private companies constructed two large dams on the Elwha River during the early 1900's for the purpose of generating electrical power. Elwha Dam, constructed during the period 1910-13, is a 105-ft high concrete gravity dam located 4.9 miles upstream from the river's mouth (Figure 2). Elwha Dam impounds Lake Aldwell, which has a surface area of 267 acres, and a storage capacity of 8,100 acre-ft at an elevation of 197 ft (see attached aerial photographs in Appendix A). Glines Canyon Dam, built in 1927, is a 210-ft high concrete arch dam located 13.6 miles upstream from the river's mouth (Figure 3). Glines Canyon Dam impounds Lake Mills, which has a surface area of 415 acres and a storage capacity of 40,500 acre-ft at an elevation of 590 ft. Both dams are operated as run-of-the-river facilities and do not provide flood control.

Figure 2. Elwha Dam, Powerplant, and Spillway.

Figure 3. Glines Canyon Dam, Spillway, and Powerplant

Although the projects helped in the early development of the peninsula by Euro-American settlers, the reservoirs inundated important cultural sites of the Lower Elwha Klallam Tribe, blocked the migration path for several species of salmon and trout, and severely limited the downstream supply of sediment and nutrients necessary for fish spawning. The removal of Elwha and Glines Canyon Dams has been proposed to fully restore the Elwha River ecosystem and native anadromous fisheries in a safe, environmentally sound, and cost-effective manner.

The U.S. Department of the Interior has recently purchased Elwha and Glines Canyon Dams in preparation for their removal. One of the major challenges in removing these two dams is the management of nearly 18 million yds^3 of sediment trapped within the two reservoirs. Large sediment loads are transported along the Elwha River from the upper watershed downstream to the reservoirs. With the dams in place, about one-sixth of the fine-grained sediment load is transported through the reservoirs and downstream river channel to the mouth, while the remainder is deposited along the reservoir bottoms. All of the coarse-grained sediment is trapped in the reservoirs as delta deposits located at the upstream end of each reservoir (Figure 4). The width of the reservoirs and their deltas is about ten times greater than the width of the alluvial river channel. Of the total sediment volume, 13 million yds^3 is trapped in Lake Mills (the upstream reservoir behind Glines Canyon Dam) and 5 million yds^3 is trapped in Lake Aldwell (behind Elwha Dam). About one half of the sediment in Lake Mills is coarse grained (sand-, gravel-, and cobble-sized) and the remaining half is fine grained (silt- and clay-sized). About one-third of the sediment in Lake Aldwell is coarse grained while the remaining two-thirds are fine grained.

Figure 4. Lake Mills Sediment Delta.

1.2 Monitoring Plan Objectives

The objective of the Elwha River Restoration Sediment Monitoring Plan is to identify the critical monitoring parameters needed to evaluate the changes in physical river processes and characteristics both during and following the removal of the two dams on the Elwha River. The plan deals with the river's hydrologic, hydraulic and morphologic characteristics, sedimentation processes, interactions among flow and sediment transport, and aquifer responses. This plan is based on feedback from a workshop held in August 2001. During this workshop, a small group of technical specialists generated ideas on the types of monitoring that should be performed in order to: (1) provide information in a real-time environment that will assist project management in decisions regarding the actual removal of the two dams, and (2) provide valuable information on a longer-term scale that will both identify and quantify physical processes associated with ecosystem restoration following dam removal. The monitoring plan identifies not only what the potential monitoring parameters might be, but also how each one ties to the real-time dam removal, the long-term ecosystem restoration, or potentially both. For example, monitoring of the reservoir delta will provide critical information needed to evaluate the timing of dam removal and reservoir drawdown. Over a longer time period, this information will also be very useful to determine how the new river channel and flood plain will develop in the former reservoir. Other details provided in the plan include the parameters to be measured, their frequency and location.

1.3 Dam Removal and Sediment Management Plan Summaries

Detailed dam removal plans have been developed for the removal of all structures at Elwha Dam and for the removal of the concrete arch section at Glines Canyon Dam (Hepler and Scott, 1996). The major steps for dam removal include decommissioning of the powerplants, site access improvements and mobilization, river diversion, structure removal, waste removal and disposal, and site restoration. Both Elwha and Glines Canyon Dams will be removed concurrently over a two to three-year period. Dam removal and reservoir drawdown will not occur during certain periods designated as fish windows (see section 1.4). The start of the physical removal of the two dams would begin following the completion of water treatment plants designed to deal with high sediment loads that will occur as a result of dam removal activities. The present schedule calls for dam removal to begin in 2008.

The plan to remove Glines Canyon Dam includes blasting a series of about 20 notches in the concrete arch dam to drain and lower the reservoir in 7.5-foot increments. The notches will be blasted on alternating sides of the dam. Each notch will be about 25 ft wide, 15 ft deep, and 7.5 ft lower than the preceding notch on the other side of the dam. Low flows up to 1,500 ft^3/s will be contained in the notch. Higher flows will overtop the remaining arch section of the dam. After the reservoir drains through each successive notch, the layer of dam exposed above the reservoir level will be cut into large blocks and removed by a crane. This work could only occur during low-flow periods (up to 1,500 ft^3/s).

The plan to remove Elwha Dam includes incrementally blasting and excavating a deep river diversion channel through the bedrock spillway on the left abutment. About half of the reservoir depth will be slowly drained through this diversion channel in increments varying from 5 to 15 ft. After the reservoir level has receded, and while the river continues to be diverted through this channel, the upper half of Elwha Dam, and the fill material placed behind the dam (for the repair after its initial failure in 1913), will be removed. The remainder of Elwha Dam will be removed in 5-foot increments while the river is diverted through notches blasted in the dam.

The river erosion alternative was selected by the Secretary of the Interior as the plan to manage the nearly 18 million yds^3 of reservoir sediment (Olympic National Park, 1996 and U.S. Department of the Interior, 1997). This sediment management plan will allow the Elwha River to erode and transport a portion of the reservoir sediments downstream by natural processes (without hydraulic or mechanical dredging). Depending on river flows, about one-quarter to one-third of the coarse sediment (sand and gravel) and about one-half to two-thirds of the fine sediment (silt and clay) are expected to be eroded from the two reservoirs as a result of dam removal, with the balance re-vegetating and remaining stable over the long term as sediment terraces along the former reservoir margins (Randle and others, 1996).

This alternative requires mitigation for expected impacts to water quality from the release of fine (silt- and clay-sized) sediments carried in suspension, and for potential impacts to downstream flood stages and river channel migration from the deposition of coarse (sand-, gravel-, and cobble-sized) sediments on the river bed. The overall restoration plan contains many elements including:

- During dam removal, river flows passing through a diversion channel around Elwha Dam and through alternating notches cut into Glines Canyon Dam.
- Inducing reservoir sediment erosion through controlled increments of dam removal and reservoir drawdown.
- Protecting water quality and quantity for existing water users by replacing the existing diversion dam, adding new wells, and building new water treatment facilities.
- Addressing environmental and cultural issues by planning work shutdowns during fish migration periods, restoring the cultural sites at Elwha Dam to near pre-dam conditions,

retaining certain structures at Glines Canyon Dam for historic preservation and public interpretation.

1.4 Integration with Biological and Water Quality Monitoring Plans

In addition to monitoring physical processes during and following dam removal, it will also be necessary to monitor biological and water quality components. The biological monitoring will help quantify changes in the river that affect salmonid use and habitat. The biological monitoring is also needed to manage “fish windows” that have been established to protect fish that may be migrating upstream to tributaries or downstream to the sea. Reservoir drawdown will not be allowed during these fish windows (Table 1). The November to December window provides an opportunity for adult chum and coho salmon to enter the river. The May to June window provides for emigration of smolts as well as the possible entry of a portion of the winter steelhead run. The August to September window coincides with the return of adult chinook salmon (listed under ESA) and adult pink salmon.

Table 1. Fish Windows are time periods where reservoir drawdown will not be permitted.

Year of reservoir drawdown	Begin Fish Window	End Fish Window
1	November 1st	December 31st
2	May 1st	June 30th
2	August 1st	September 14th
2	November 1st	December 31st
3	May 1st	June 30th
3	August 1st	September 14th
3	November 1st	December 31st

The water quality monitoring will help identify critical water quality issues that might need to be addressed in order for water users downstream of the dams to adequately treat the water for municipal and industrial uses. The primary water quality concern is the high turbidity that is expected from the high concentrations of suspended sediment that will be eroded from the reservoirs. Because many processes evaluated as part of this plan can also be used for the biological and water quality monitoring, integration between the plans is needed prior to project implementation. A biological monitoring workshop was held in March 18-19, 2003 in Port Angeles, Washington to begin generating ideas and funding sources for the biological monitoring effort. This workshop was led by key fisheries scientists involved in the Elwha Restoration Project.

One example of integration between the biological and physical processes monitoring is the response of the river channel to large woody debris. Historically, large woody debris was a key component in providing fish habitat and complexity in the river channel. Log jams can also affect the physical planform of the river depending on the size and location of the jam. Currently, there is a lack of natural log jams in the river channel due to the upstream reservoirs trapping woody debris and historically, physical removal of log jams from the river. Some initial data collection has already begun to evaluate the physical and biological responses to engineered log jams (ELJs) (McHenry et al., 2000). This effort was expanded in 2000 as a pilot study between the Lower Elwha Klallam Tribe in partnership with the National Marine Fisheries Service to increase the level of detail in the biological monitoring program. A proposal was submitted to carry out a five-year evaluation of engineered log jams on the Elwha River and incorporate results into future ELJ construction designed to create fish habitat. Quantification of the changes in physical habitat resulting from ELJs will focus primarily on changes in topography and fish habitat, a reach-scale wood budget, and flow velocities within ELJs (McHenry, 2001).

Another example of integration is the monitoring of deposition of fine-sized sediments resulting from dam removal. Short-term deposition of fine-sized sediments in spawning areas could result in temporary clogging of the void spaces between gravels. This will have an adverse impact on spawning, but may not be permanent as subsequent high flows rework the spawning gravels and transport the fines downstream. Monitoring of the thickness and gradation of deposition of sediments released from the reservoirs is planned at 22 cross sections throughout the river downstream of the two dams (see Section 5.4). Additional monitoring of sediment deposition in fish habitat areas, accumulation of fines in spawning areas, or impact on hyporheic exchange could also be considered as part of the biological monitoring effort.

An example of water quality and physical monitoring integration is the measurement of suspended sediment transport between the dams and water treatment facilities. Knowing how quickly suspended sediment is transported from the reservoirs is needed to plan water treatment plant operations, to determine the impacts on fish, and to manage the fish windows.

2.0 PREVIOUS INVESTIGATIONS AND SURVEYS

Several investigations have already been undertaken that shed some light on the physical processes currently operating in the Elwha River. These studies have been helpful in making some predictions about future changes as a result of dam removal. A brief summary of these investigations is provided below.

2.1 The Elwha Report (January 1994)

This report provides a good overview of the project including how it was legally enacted. The report discusses the impact the dams have had on the environment, and the various alternatives that were evaluated to meet the goals set for restoration of the Elwha River. The Elwha Report concluded that removal of both dams was feasible and necessary to fully restore the ecosystem and native anadromous fisheries of the Elwha River. The report also provides information on the plan for dam removal and the associated legal and environmental requirements. Finally, potential costs and an estimated timetable for dam removal are presented.

2.2 Lake Mills Drawdown Experiment (Childers et al., U.S. Geological Survey, 2000)

The Lake Mills drawdown experiment (Childers et al., 2000) was crucial to learning about the erodibility of reservoir sediment. Lake Mills was drawn down 18 ft over a one-week period and then was held at a constant elevation for one additional week. This drawdown experiment exposed the upper layer (12- to 18-ft thickness) of coarse delta sediment to direct erosion by the Elwha River. Several types of data were collected throughout the drawdown experiment including:

- River discharge
- Suspended sediment concentration and water quality
- Bedload
- Particle size gradations and chemical composition of the upper delta layer
- Repeat cross section measurements of the delta surface (above and below water)
- Time-lapsed photography of the delta erosion
- Aerial photography

During the reservoir drawdown, vertical incision through the coarse delta sediments was very rapid, but the width of erosion was initially much less than the reservoir delta width. The eroded sediments re-deposited in the receded lake and formed a new delta immediately downstream of the initial delta front. Once the reservoir was drawn down 18 ft, the lake elevation was held constant for another week. During the period of constant lake elevation, lateral erosion processes dominated the continued erosion of the exposed delta, especially at the downstream end. The width of erosion was near zero at the delta's upstream end, but increased at a rapid rate in the downstream direction until the erosion width equaled the reservoir width at the delta face (Randle et al., 1996).

The Lake Mills drawdown experiment helped lead to the conclusions that the reservoir sediment erosion could be managed by controlling the rate of reservoir drawdown, and that not all of the sediment will be eroded from the reservoir during dam removal. The results also provided critical data needed for a new sediment erosion model. The new reservoir sediment erosion model was an empirically based, mass-balanced model (Randle and others, 1996). This model predicted the rates and final quantities of fine- and coarse-grained sediment eroded from each reservoir. The standard HEC-6 model (U.S. Army Corps of Engineers, 1993) was applied, using measured cross sections of the downstream river channels, to predict the potential for sediment deposition. The selected plan for managing the 18 million yds^3 of reservoir sediment is to remove both dams concurrently, in controlled increments, over a two-year period. Rates of sediment erosion, transport, and deposition are to be intensively monitored during dam removal. These rates will be monitored to determine if they match the values predicted by the model to within acceptable limits, before proceeding with the next increment of dam removal (U.S. Department of the Interior, 1996).

2.3 Sediment Modeling and Analysis of the River Erosion Alternative (Randle, et al, Reclamation, 1996 and Randle, 2002)

Removal of the dams requires the development and analysis of alternative plans to manage the reservoir sediment and an analysis of the effects of re-establishing the natural sediment supply to the Elwha River downstream of the dams. The natural sediment supply is defined as sediment delivered from the upstream watershed above Lake Mills that since the construction of the dams has been largely trapped in the reservoirs. Removing the dams in controlled increments and allowing reservoir sediment to erode and be transported downstream through natural processes was the alternative evaluated in this report (Randle, et al, 1996). The impacts of this alternative on the river's sediment concentration, riverbed aggradation, and corresponding increases in flood stage were predicted from the results of reservoir drawdown testing at Lake Mills and a series of computer models. In the original modeling effort, a period of three years and four months was simulated for each of four different hydrologic scenarios with dam removal occurring in two years. The period of model simulation was later extended by an additional 10 years along with the removal of Glines Canyon Dam at a slower rate and occurring over a three-year period (Randle, 2002).

Model results predicted that 23–31 percent of the coarse sediment (sand, gravel, and cobbles) and 50 to 60 percent of the fine sediment (silt- and clay-size particles) will be eroded from the two reservoirs following dam removal (Randle, 2002). The remaining sediment will be left behind along the reservoir margins as a series of terraces.

Fine sediment concentrations released from the reservoirs will tend to be high (100 to 10,000 ppm) during periods of dam removal with peak concentration occasionally as high as 20,000 to 40,000 ppm depending on natural river flows (Randle, 2002). Release concentrations are expected to be lower during periods when the reservoirs are being held constant, but concentrations are still expected to be generally higher than under present conditions. During dam removal, average concentrations of fine sediment are expected to be about 100 times greater than under present conditions below Elwha Dam. After the dams are removed, fine sediment concentrations will be low and near natural conditions during periods of low flow. Concentrations will be high during progressively higher flood flows as erosion channels widen in the reservoir areas. Concentrations are expected to return to natural levels from the upstream watershed above Lake Mills within 3 to 5 years after dam removal. After dam removal, fine sediment concentrations are expected to be about 10 times greater than under present conditions below Elwha Dam with peak concentration occasionally reaching between 1,000 and 10,000 ppm.

Coarse sediment will deposit in river pools in the relatively steep reach between the two lakes and will increase 100-year-flood stages up to 0.5 ft. In the more mildly sloping reach below Elwha Dam, general riverbed aggradation will occur that will likely cause the river to migrate laterally, especially near the mouth. Over the short term (up to five years), this could potentially increase river stages during the 100-year flood by 0 to 2.5 ft, depending on location, with an average increase of less than 1 foot. Over the long term (50 years), aggradation could continue and increase existing river stages during the 100-year flood 0 to 5 ft (depending on location) with an average increase of 2.5 ft. Coarse sediment is predicted to enlarge the delta at the river's mouth to a size and character similar to that of pre-dam conditions (Schwartz, 1994).

The study concluded that with monitoring and mitigation, the "river erosion alternative" constitutes a viable sediment management plan for the removal of Glines Canyon and Elwha Dams. Extensive monitoring and control of the dam removal rate are needed to manage or avoid problems with riverbed aggradation, flooding, and water quality.

2.4 Alluvium Distribution in Lake Mills and Lake Aldwell (Gilbert and Link, Reclamation, 1995)

This report presents the results of a geologic mapping and sampling program conducted at Lake Mills and Lake Aldwell (Reclamation, 1995). The purpose of this investigation was to estimate post-dam sediment distribution, grain-size gradations, and sediment volumes in each of the reservoir basins.

The study concluded that since the construction of Glines Canyon Dam in 1927, a 3,000-ft long, 70 to 80 ft thick (at its maximum) delta has been formed at the upstream end of Lake Mills. Sediment sizes were found to range from silt to boulders. The larger particles (gravels, cobbles, and boulders) were found to be present in the delta at the upstream end of the reservoir, and finer-sized sediments (sands and fine gravels) were found in the downstream reach. Of the 13.8 million yds^3 of sediment in Lake Mills, the study found that approximately 51 percent is located in the delta area, 38 percent is along the reservoir bottom and side slopes, and the remaining 11 percent is distributed in Rica Canyon and at the mouths of the major tributaries in the Lake Mills basin. Approximately 48 percent of the total post-dam sedimentation volume in Lake Mills was found to consist of silt and clay, 37 percent of sand, and the remaining 15 percent of gravel, cobbles, and boulders.

Since the construction of Elwha Dam, from 1910 to 1913, the study found that a narrow, 2,500-ft long, 18 to 24 ft thick delta has been created at the upstream end of Lake Aldwell. The post-dam delta is nested in older river terrace deposits that are locally up to 16 ft above normal reservoir elevation of 197 ft. Sediment grain sizes in Lake Aldwell range from gravel to boulders at the upstream end, and are mostly sand and silt at the front of the delta (downstream end). Of the total 3.9 million yds^3 of sediment in Lake Aldwell, the study found that approximately 46 percent is located in the delta, and 54 percent mantles the reservoir floor and side slopes. Silt and clay account for 67 percent of the reservoir sediment in Lake Aldwell, a much larger percentage than in the upstream Lake Mills. About 28 percent of the reservoir sediment consists of sand, and the remaining 5 percent consists of gravel, cobbles, and boulders.

2.5 Alluvium Distribution in the Elwha River Channel between Glines Canyon Dam and the Strait of Juan de Fuca, Washington (Gilbert and Link, Reclamation, 1996)

This investigation was undertaken to characterize the existing sediment gradation ranges and distribution of the active channel armor and sub-armor layers downstream of the two dams (Reclamation, 1996). Sediment mapping, limited laboratory sampling, and visual sediment classifications were incorporated to determine the sizes of sediment present in the riverbed. Results from the study showed that between RM 13.5 (just downstream of Glines Canyon Dam) and RM 4.0, bedrock controls the river gradient and extensive armoring has occurred due to the trapping of sediment in the upstream reservoir. Between RM 4.0 and 2.5, the study found the river to be in transition from a bedrock controlled channel gradient to a zone lacking such control. Downstream of RM 2.5 to the mouth, bedrock control of the river gradient was found to be absent and moderate channel migration and downcutting was present. Some channel armoring was also found in this reach, but the extent and size of the armoring was less than in the upstream reaches.

At 34 cross sections, fluvial terraces were also observed. Terrace elevations above the river channel ranged from 3-4 ft, to a maximum of 15-18 ft. The fluvial sediment present in these terraces and in sub-armor layers was noted as the best indicators of sediment sizes that were present in the riverbed prior to dam construction.

2.6 Sediment Transport, Channel and Beach Morphology (Hosey and Associates, 1988)

Hosey and Associates Engineering Company conducted a brief reconnaissance survey of the lower Elwha River in 1987 at the request of the owner of the dams at that time, James River II, Inc (Hosey and Associates, 1988). This study briefly discussed the geology of the Elwha River and concluded that the Quaternary glacial, landslide, and alluvial deposits are the most erodible and accessible sources of sediment for the Elwha River.

Hosey and Associates also performed an initial investigation of the sediment supply on the Elwha River based on estimates of sediment transport. The study also discusses the potential sediment sources from landslides, glacial erosion, and logging roads. About 970,000 yd^2 of landslide scars were measured from 1981 aerial photographs in the watershed upstream of Glines Canyon Dam. Glaciers were noted as covering about 1.17 mi^2 of area in the upper Elwha basin. Estimates were also made as to the extent and size of the deltas in Lake Mills and Lake Aldwell.

Fifteen sampling sites were also established to document the topography, local water surface slope, the armor layer, and the sub-armor layer. In addition, the report discusses the geomorphology of the undisturbed river channel upstream of Lake Mills and the impacts of the two dams and reservoirs both at the project sites and in the downstream river channel. Sites were observed where large log jams had formed causing a local backwater effect upstream. The report indicates that the reaction of the river channel to these log jams has been to continue to deposit sediment upstream of the jams and to migrate back and forth until a portion of the jam can be breached and the river channel bed elevation is able to reconnect with that of the channel bed downstream of the log jam. Hosey and Associates also note that two large natural landslides were observed at RM 20 and 21.9, both of which continue to contribute sediment to the river.

Downstream of the dam, historical aerial photographs were compared to evaluate channel changes at the mouth of the river and changes at Ediz Hook for the period 1891 to 1997. Hosey and Associates observed various phases of stability, retreat, and advance of the shoreline at the mouth of the Elwha River. Possible causes of these changes include a lack of sediment input from the river due to impoundment in the reservoirs, an increase in sediment from glacial outwash, and a riprap jetty built across the river mouth in the mid 1960's to stop channel migration. Ediz Hook has been relatively stable since riprap, gravel, and cobble have been placed to prevent further erosion and breaching from occurring. Historically, sediment supply to Ediz Hook was reduced by a bulkhead created for a water-supply pipeline. The report concludes that the reduction in sediment caused by the construction of the Elwha and Glines Canyon Dams has not been a significant cause of erosion of Ediz Hook because sediment is available from other sources in the lower river and from bluffs just west of the hook.

2.7 Beach Geomorphology (Schwartz, 1994)

A report by Maurice Schwartz for the Lower Elwha Tribal Council provides information on the beach geomorphology at the Elwha River delta and how the coastal processes may be impacted by removal of the dams (Schwartz, 1994). This report recommends surveying the beach topography and mapping offshore bottom sediment both prior to dam removal, during the removal, and for a period of time after the removal.

Schwartz notes that near Ediz Hook, the potential capacity for eastward net shore-drift ranges from 270,000 yds^3/yr to 370,000 yds^3/yr. He also notes that while 350,000 yds^3/yr of sediment was likely transported to Ediz Hook prior to dam construction, the dams have reduced this volume to 90,000 yds^3/yr. The conclusion is drawn that the system's sediment transport capacity is currently greater than its sediment supply.

The study also reports that the existing beach needs to be nourished due to the lack of sediment over the last 100 years. Schwartz estimates that following the removal of both dams, 123,000 yds^3/yr to 209,000 yds^3/yr of sediment will be discharged from the Elwha River into the Strait. It is expected that the coarser particles will drop out at the river's mouth, while sand and pebbles will be transported out to the east, building a delta beach sector before migrating to the shore in front of the east bluffs and beyond Ediz Hook. Schwartz notes that suspended sediment levels following dam removal should be of no greater concern than for other rivers in the region.

Schwartz, including his summary of the Hosey & Associates (1988) report and U.S. Army Corps of Engineers documents, provides qualitative and quantitative information on shoreline position and delta changes over time. A much longer-term analysis of shoreline retreat is presented by Schwartz that extends over the past 9,000 years before the present (ybp). Mapping intervals are: 9,000 ybp, 7,000 ybp, 5,000 ybp, 2,000/1,000 ybp, present. Using a preliminary comparison of the map scales, Schwartz suggests that the shoreline has retreated southward a few feet per year over this long period.

Schwartz also provides quantitative values for littoral drift and river contributions to coastal sediments:

- Littoral drift causes sediment to be transported mainly from west to east along the coastline near the Elwha River mouth and delta.
- Littoral transport of beach sediment eastward from Freshwater Bay to the Elwha River mouth is about 25,000 cubic yards per year.
- The west bluff that has been eroding in recent years (with the Elwha River cutting at its base) contributes about 25,000 cubic yards per year of sand and gravel.
- Littoral transport of beach sediment eastward along the delta east of the Elwha River is presently about 90,000 cubic yards per year; In the pre-dam era this may have been about 350,000 cubic yards per year; the general transport capacity is estimated to be 270,000-370,000 cubic yards per year.
- A flood in 1990 caused erosion of the west bluff and led to formation of an offshore bar containing about 25,000 cubic yards of material.
- During floods the suspended sediment concentrations at the mouth are up to 1,000 ppm (parts per million).

Water samples collected occasionally during winter months in one season provided a linear correlation between suspended sediment concentration and water turbidity (locations not known). Therefore, it may be possible to develop suspended sediment concentration and water turbidity relationships for future monitoring efforts.

2.8 Flooding Impacts Associated With Dam Removal (Lencioni, U.S. Army Corps of Engineers, 1995)

This report provides a technical analysis of the potential flooding impacts associated with removal of the Elwha and Glines Canyon Dam, as needed for the Elwha River Restoration Project Environmental Impact Statement (Lencioni, 1995). The report presents modeled results for the 100-year flood plain inundation from the mouth of the Elwha River upstream to Elwha Dam, and from the upper end of Lake Aldwell upstream to Glines Canyon Dam. From a separate study, aggradation of the riverbed was predicted to occur in several areas as a result of the dam removals (Randle, et al, 1996). Deposition on the riverbed can often result in increased flood stages. Where the deposition was predicted to increase flooding as a result of the dam removals, suggested mitigation options and costs are presented in this study to protect the property and/or infrastructure.

The report mentions that the flooding impacts resulting from dam removal are directly attributable to the sediment aggradation on the riverbed. Therefore, Lencioni recommends that a formal channel sediment surveillance program be established during dam removal to monitor aggradation and channel migration in order to properly evaluate flooding impacts and mitigation options. Specific monitoring activities are recommended as follows:

- Annual channel surveys at 10-15 selected locations downstream of Glines Canyon Dam
- Five years after dam removal, continue channel surveys once every 5 years, or after every major flood
- Comparison of channel surveys with predicted cross sections, and consideration for mitigation options if aggradation exceeds predicted amounts
- Monitoring of lateral migration of the river channel and appropriate mitigation if necessary (bank protection)

Since the completion of the report by Lencioni, the channel bottom and flood plain were resurveyed (2001) and a new hydraulic model for existing conditions was developed by the Corps of Engineers (report in progress). Estimates for post-dam removal water surface elevations were also developed based on the 1996 sediment modeling results (Randle, 2002).

2.9 Water Quality Analysis and Mitigation Measures (Bowser, et al., Reclamation, 1997)

A report was developed to compare the pre-dam water quality conditions with the expected conditions during dam removal and post-dam removal conditions (Bowser, et al., 1997). Due to the fact that the two dams trap the majority of sediment in the upstream reservoirs, the present water quality downstream of the dams is favorably impacted from a water supply and treatment perspective. Short duration storms do occur during which a portion of the silt- and clay-sized sediment are suspended and transported downstream past the dams. Water released from the two reservoirs can cause increased water temperatures in the downstream river channel, particularly during the summer months.

During short-term dam removal activities, suspended sediment levels will be higher than current conditions and will have the largest impact on water quality. Levels of suspended sediment are also expected to be greater during high flows. During low flows, suspended sediment levels are predicted to be similar to current levels. The report notes that the amounts of fine sediment transported downstream during dam removal will be highly variable depending on flow and dam removal activities. Water quality impacts over the long-term will be most affected by levels of suspended and dissolved solids, including total organic carbon and turbidity. Dissolved oxygen content should not be affected, and water temperatures should improve.

The report also notes that groundwater quality and quantity could be affected in some areas. Wells near the reservoir will have lower water tables as the reservoirs are drawn down during removal. Wells connected to the river may experience higher turbidity levels affecting the quality. In areas where aggradation occurs on the riverbed, it is expected that the ground-water levels will rise and in the lower valley, some septic systems may be affected.

2.10 Previous Surveys and Historic Aerial Photography

Several surveys of the reservoirs, river channel, and coastal beaches have been performed by a number of different organizations at various intervals. Maps of the coastal areas date back to the late 1800's. A "timber cruise" survey was conducted along the river valley during the early 1900s. A similar "timber cruise" effort was made on the Dungeness River in 1913 and it is likely that the Elwha survey was part of the same county wide effort to document potential timber harvest areas. A survey of the Lake Mills Reservoir area was conducted in 1927 prior to the construction of Glines Canyon Dam (Jones, 1927). However, no pre-dam survey was ever found for Lake Aldwell.

Reclamation began conducting surveys of the reservoirs and river channel in 1994. During that year, Reclamation surveyed the bottom topography of both Lake Mills and Lake Aldwell. Also during that year, Reclamation and the Corps of Engineers established a network of 33 cross sections between the river's mouth and Glines Canyon Dam. The average spacing of the cross sections was 0.2 miles between the river mouth and Elwha Dam (river miles 0 to 5). Between Lake Aldwell and Glines Canyon Dam (river miles 8 to 13), the average spacing was 0.5 miles. In 1995, an additional survey was conducted to document water surface elevations and hydraulic structures associated with the rock diversion dam (near river mile 3.4). In 2000, additional cross section surveys were conducted to determine the 100-year floodplain in the vicinity of the Dry Creek Water Association wells (river mile 3.8).

In 2001, a set of new surveys were conducted to intensify the topographic coverage of the river channel and flood plains and to document the changes in the river channel position since 1994. The surveys conducted in 2001 included the following activities:

- LIDAR survey of the flood plains and terraces was conducted during February 2001 from the mouth to the upstream end of Lake Mills (river miles 0 to 15).

- Establishment of a G.P.S. control network along the river corridor from the mouth to Glines Canyon Dam.

- Bathymetric survey of the river channel was conducted during May 2001 from the Glines Canyon Powerplant downstream to Lake Aldwell and from Elwha Dam downstream to the mouth. This survey was conducted from a raft using G.P.S. instruments, depth sounder, and laptop computer. The longitudinal river profile from this survey is presented in figures 2.1 to 2.4.

- The river channel and LIDAR survey data were combined to produce a digital elevation model of the river corridor including the bathymetry of Lake Mills and Lake Aldwell based on the 1994 survey data.

The most recent aerial photography available at the time of this report writing is from June/July timeframe of 2005 that was collected and ortho-rectified by the Washington Department of Natural Resources. Aerial photographs were also obtained on August 5, 2000 and ortho-rectified by the Washington Department of Natural Resources (see attached aerial photographs in Appendix A). The 2000 aerial photographs were used to create a G.I.S. database of the river corridor from the river mouth to the upstream end of Lake Mills. This G.I.S. database also includes all the survey data collected since 1994 and the 1994 aerial photographs obtained by USGS. Aerial photographs were also taken along the river corridor at various distances from the mouth. The years that historical aerial photographs are available include 1939, 1956, 1965, 1971, 1977, 1981, 1990, 1994, and 2000. The Lower Elwha Klallam Tribe has compiled this data into their G.I.S. database.

2.11 Available Gage Data

Gaging station data has been collected by U.S. Geological survey in the Elwha basin as described in Table 2.

Table 2. Gaging station data collected by USGS in the Elwha River basin.

Station	Location	Drainage Area	Maximum Discharge Recorded	Measurement Parameter					Notes
				Water Stage	Discharge	Turbidity	Temperature	Sediment	
12044900 Above Lake Mills	Latitude 47°58'13", Longitude 123°35'22", on right bank 30 feet upstream from Cat Creek, 2.5 miles above Glines Canyon Dam RM16.2.	198 mi^2	17,400 cfs 11-8-1995	March 1994 to May 1998, February 2004 to September 2005	March 1994 to May 1998, February 2004 to September 2005	December 2003 to September 2005	April 1994 to May 1998, February 2004 to September 2005	March 1994 to December 1997	Real-time data for water year 2006; stage and discharge will continue in 2007. Prior to February 2004, gage on left bank 0.2 miles upstream at different datum.
12045500 McDonald Bridge	Latitude 48°03'18", Longitude 123°34'55", on right bank near site of the McDonald Bridge (removed), 0.7 mile above from Little River, 1.1 miles upstream of highway 101 Bridge, 4.9 miles below Glines Canyon Dam, RM 8.6	269 mi^2	41,600 cfs 11-18-1897	October 1897 to December 1901, October 1918 to current year	October 1897 to December 1901, October 1918 to current year	February 2004 to present	April 1976 to August 1977, October 1994 to April 1998, April 2004 to current year	April 1994 to September 1995; Miscellaneous sediment measurements October 1995 to September 1977	Real-time data for water year 2006. Stage, discharge, and turbidity will continue in water year 2007.
12046260 River Mile 3.5 at Diversion Intake	Latitude 48°06'53", Longitude 123°33'07", on right bank 3.5 miles upstream from mouth, and at RM 3.5.	318 mi^2				February 2004 to September 2005			Discontinued as of Oct 1, 2005

3.0 RESOURCE MANAGEMENT OBJECTIVES AND THE RELATIONSHIP TO PHYSICAL PROCESS MONITORING

The objective of the Elwha project is to fully restore the Elwha River ecosystem and its native anadromous fisheries. Two primary tasks are required to successfully accomplish this objective. First, the Elwha and Glines Canyon Dams will be removed. The current dam removal plan will accomplish removal of the two dams within a 3 year time period. This task will involve both the successful removal of the dams, including disposal of construction materials, and the safe and beneficial management of reservoir sediment releases. The second task involves the post-dam restoration of the fluvial, riparian, and aquatic ecological systems downstream from the dams and on the former reservoir beds. This second task will involve both relatively short-term proactive resource management actions as well as natural "healing" and ecosystem recovery that will occur over a timeframe of years to decades. For example, planting on exposed reservoir sediments may be done to speed up the recovery of floodplain vegetation, or engineered log jams may be used to speed up the recovery of large woody debris within the channel used for habitat. This section of the report describes the categories of physical process monitoring, and how results from this monitoring are linked to potential management actions related to dam removal activities. Section 4 describes how the adaptive management monitoring plan will be implemented and operated in a real time manner during dam removal.

3.1 Adaptive Management versus Restoration Monitoring

This sediment monitoring plan discusses physical process monitoring tasks designed to support each primary task of the Elwha project – dam removal and ecosystem restoration. While there may be overlap in monitoring approaches, there are differences in the objectives between physical processes monitoring in support of the dam removal tasks (*Adaptive Management Monitoring*) as distinct from monitoring in support of better understanding ecosystem restoration processes (*Restoration Monitoring*). For purposes of this plan, adaptive management monitoring is used to describe monitoring tasks that are necessary to accomplish dam removal. Restoration monitoring is used to describe additional tasks that may not be necessary to accomplish dam removal, but would be used to measure project performance, would result in a body of scientific knowledge applicable to both understanding and interpreting natural river restoration and healing, and would be applicable to the design of future river restoration projects in other locations. There is currently only funding for adaptive management monitoring activities, and, therefore, the most detail and emphasis are placed in this plan on adaptive management tasks. However, restoration monitoring ideas are presented in this plan in the hope that interested parties will pursue funding options for these learning opportunities.

In many cases, information from adaptive management monitoring could provide baseline data and be integrated with restoration monitoring results. For example, cross section survey data will be collected at particular locations as part of the adaptive management monitoring. This network of cross sections could be expanded to include more closely spaced cross sections to accomplish restoration monitoring goals such as more detailed tracking of channel bed changes in response to release of coarse sediment from the two reservoirs. The results from the restoration monitoring and research program would be made available to interested parties through technical reports and executive summaries.

3.2 Dam Removal Resource Management Objectives

The adaptive management sediment monitoring activities are limited to tasks necessary to monitor whether the following project resource management objectives are being met:

1. Sediment concentrations should not overwhelm the water treatment facilities or municipal and industrial wells or significantly reduce water yield of those wells
2. Sediment concentrations should not be high enough that they prevent fish from migrating into or out of the Elwha River during critical migration periods (fish windows)
3. Sediment deposition along the riverbed should not increase flood stage beyond the design limits of new flood protection infrastructure (constructed prior to start of dam removal)
4. Sediment deposition along the riverbed and flood plain should not increase the water table to a level that significantly reduces property value
5. Future channel processes should not additionally harm existing infrastructure and property beyond impacts associated with historic or existing processes
6. Dam removal should be accomplished in a safe, controlled manner that prevents large landslides from entering the reservoir or inducing a flood wave into the downstream river channel

3.3 Monitoring Categories

Sediment monitoring activities were suggested by participants at the workshop in August 2001 and were then categorized as to whether they fell into the adaptive management or restoration monitoring category based on the definitions described above (Table 3). Section 5 of this report provides more details on implementing each of the categories listed, and how the adaptive management data will be tied to potential management actions.

Table 3. Subjects of Adaptive Management Monitoring and Restoration Monitoring		
Monitoring Category	**Adaptive Management**	**Restoration**
Reservoir Sediment Erosion and Redistribution ➢ Delta erosion and downstream progression ➢ Release of coarse sediments from the reservoirs ➢ Re-establishment of reservoir flood plain and vegetation	X	X
River and Reservoir Hillslope Stability	X	X
Water Quality (Suspended Sediment Concentration & Turbidity)	X	X
Riverbed Aggradation and Flood Stage ➢ Bed material size measurements ➢ River water surface elevations ➢ Channel geometry	X	X
Aquifer Characteristics ➢ Water table elevations ➢ Well water yields, quality	X	X
River Channel Planform and Channel Geometry	X	X
Large Woody Debris Processes	X	X
Coastal Processes		X
Sediment Budgets (Bedload Measurements, Channel Storage Changes, Comprehensive Channel Survey)		X

3.4 Timing and Duration of Monitoring Activities

Adaptive management monitoring is intended to be highly operational and conducted in "real time." Information developed as part of adaptive management monitoring will feed back directly to project managers and be used to verify or modify dam removal scheduling, and to trigger contingency actions required to protect downstream water quality, property, and infrastructure (see Section 4 for more information on decision making process). On the other hand, restoration monitoring would not need to be processed and evaluated in conjunction with the dam removal schedule and activities. Restoration monitoring could be either short term or could continue for a longer period of time.

The timing and frequency of adaptive management monitoring tasks vary depending on the stage of dam removal. Some tasks must be accomplished prior to the start of dam removal, some during the reservoir drawdown, and others will not be initiated until the reservoir pool is essentially gone. The frequency of monitoring depends on the progression of sediment transport both in the reservoirs and in the downstream river channel. Additionally, during certain time periods dam removal activities will be temporarily halted and the frequency of some monitoring activities may be slowed or even delayed until dam removal is resumed. Dam removal will be temporarily halted when high flows result in overtopping of the dam resulting in unsafe working conditions. Dam removal will also be temporarily halted during fish windows. Fish windows are time periods established by fishery scientists during which fish migrate in the river channel downstream of Elwha Dam and it would be ideal to have low levels of turbidity in the water. Certain monitoring activities such as stream gages would continue during floods to help provide information for management decisions related to protection of downstream infrastructure, property, and residents.

Several monitoring activities will be accomplished prior to dam removal to generate a set of baseline data that will help scientists better understand the role of dam removal in changing sediment processes both during and after dam removal. In addition, collecting data prior to dam removal will allow new field data collection techniques to be explored and methods to be firmly established in a controlled setting rather than during dam removal when the river will be much more dynamic.

The monitoring timing and frequency for tasks accomplished during dam removal will depend on the stage of dam removal, results from other monitoring tasks, and the progression of sediment processes associated with dam removal. For instance, during the initial reservoir drawdown monitoring activities will focus on river erosion through the upstream deltas and the downstream progression of delta sediments. During this period the monitoring frequency will be either continuous (real-time data collection such as gage sites) or once per drawdown increment for activities that are more dependent on the progression of dam removal. As long as a reservoir pool remains during dam removal, eroded delta sediments will re-deposit as a new delta within the receding reservoir.

After the top half to two-thirds of the dam has been removed, the eroding delta sediments will be of sufficient volume to reach the dam and the reservoir pool will become completely filled in with sediment (Randle et al., 1996). At this critical point in time, further dam removal will result in the downstream release of coarse sediments. At this critical point in dam removal certain monitoring activities will occur on a one-time basis to assess the volume of sediment in the remaining reservoir pool and the stability of the exposed sediment in the former reservoir area. The results from these activities will help determine if the exposed sediments in the upstream reservoir are stable or if continuing dam removal could result in uncontrolled releases of sediment that exceed predicted levels. This will be an important stage of monitoring because uncontrolled sediment releases in excess of predicted levels could cause unanticipated flooding and water quality problems to occur.

Once dam removal is resumed, the coarse sediments released from the former reservoir area will become subject to deposition along the downstream river channel, including locations such as pools, backwater channels, eddies (recirculation zones), and flood plain edges along the river channel. At this stage in dam removal monitoring activities would be initiated that track the downstream progression of coarse sediments. The frequency of these tasks will depend on the speed of the sediment wave once it is released from the reservoir.

Within three to five years following the completion of dam removal, sediment impacts associated with dam removal are predicted to decrease to minimal levels. However, as long as significant sediment impacts still exist adaptive management activities such as operation of the water treatment plant and potential mitigation associated with unanticipated flooding or bank erosion will continue. In order to determine when sediment impacts downstream of the dams have decreased to negligible levels, certain monitoring activities will continue after dam removal is completed. It is planned to have these monitoring activities continue for three years following dam removal, but if unanticipated sediment impacts are still occurring monitoring would need to continue until the impacts can be deemed non-critical to water quality, flooding, or other safety issues that would require adaptive management actions.

Criteria to determine when to stop adaptive management monitoring activities were developed based on when the erosion of reservoir sediments has essentially stopped or slowed to levels such that suspended sediment concentrations and turbidities have reached natural conditions in the Elwha River downstream from the former dams (see Appendix B). "Natural levels" are defined as equivalent to what they would be had the dams not been in place, and will be determined based on comparison to levels in the upstream, undisturbed watershed (above Lake Mills). A determination that natural conditions have been achieved for suspended sediment concentration and turbidity would be based on achieving the following three conditions:

<u>Condition 1</u>: Stable relationship between upstream and downstream suspended sediment concentrations or turbidities based on a comparison of weekly averages above a threshold, weekly maximum values, or weekly sediment loads.

<u>Condition 2</u>: No significant change in reservoir sediment volume. Condition 2 would be met when the net erosion of reservoir sediments since the last semi-annual measurement in the former Lake Mills and Aldwell is insignificant (less than 5 percent) relative to the long-term average annual sediment load of the Elwha River.

<u>Condition 3</u>: Hydrologic and geomorphic evidence of stabilized reservoir sediments. Condition 3 would be met when the remaining reservoir sediment terrace banks are determined to have attained a level of geomorphic stability comparable to the reference reach at Krause Bottom (Geyser Valley).

4.0 IMPLEMENTATION OF ADAPTIVE MANAGEMENT MONITORING PROGRAM

As mentioned in the introduction section of this report, detailed dam removal plans have been developed for the removal of all structures at Elwha Dam and for the removal of the concrete arch section at Glines Canyon Dam (Hepler and Scott, 1996). The river erosion alternative was selected by the Secretary of the Interior as the plan to manage the 21 million yds^3 of reservoir sediment trapped behind the two dams (Olympic National Park, 1996 and U.S. Department of the Interior, 1997). This alternative resulted in mitigation projects to deal with expected impacts to water quality from the release of fine (silt- and clay-sized) sediments carried in suspension, and for potential impacts to downstream flood stages and river channel migration from the deposition of coarse (sand-, gravel-, and cobble-sized) sediments on the river bed. These mitigation activities are being accomplished prior to the start of dam removal based on the best available predictions of the either temporary or long-term sediment impacts as a result of the removal of the two dams.

However, a sediment management project of this scale has not been previously accomplished. There is some uncertainty associated with the physical process predictions associated with the removal of the Elwha and Glines Canyon Dams and these processes can have a significant influence on sediment management actions, including the maximum rate of dam removal. Therefore, the adaptive management monitoring program was developed to monitor the response of the reservoir and downstream river channel to dam removal activities. In the event that the actual sediment impacts resulting from dam removal are greater than predicted, adaptive management responses have been developed that will include several options for managing the sediment impacts in conjunction with dam removal activities.

A successful adaptive management monitoring program requires effective communication between the technical groups who are conducting the monitoring and data analysis, resource managers who make decisions regarding adaptive management responses, project personnel who are responsible for implementing those decisions, and the general public who may be directly or indirectly affected by the adaptive management actions. The adaptive management monitoring has a real-time focus, so that preliminary monitoring results would generally be available within hours, days, or weeks after collection. The organizational process and implementation of the adaptive management monitoring program is described below.

Prior to dam removal, a more detailed implementation plan will need to be developed by the ONP geomorphologist assigned to the Elwha project with assistance from Reclamation's Sedimentation and River Hydraulics Group and the National Park Service Water Resources Division. The implementation strategy would address the specific adaptive management monitoring tasks, logistics, and the details for dissemination of this information.

4.1 Organization Structure of Adaptive Management Monitoring Program

The organizational structure of the Adaptive Management Monitoring Program would consist of the Elwha Project Team Leader, the on-site Geomorphologist, a technical support team, and data collection teams (Figure 5). This Elwha Project Team Leader would communicate with the Project Management Team and the Reclamation Construction Office who would oversee the dam removal contractor.

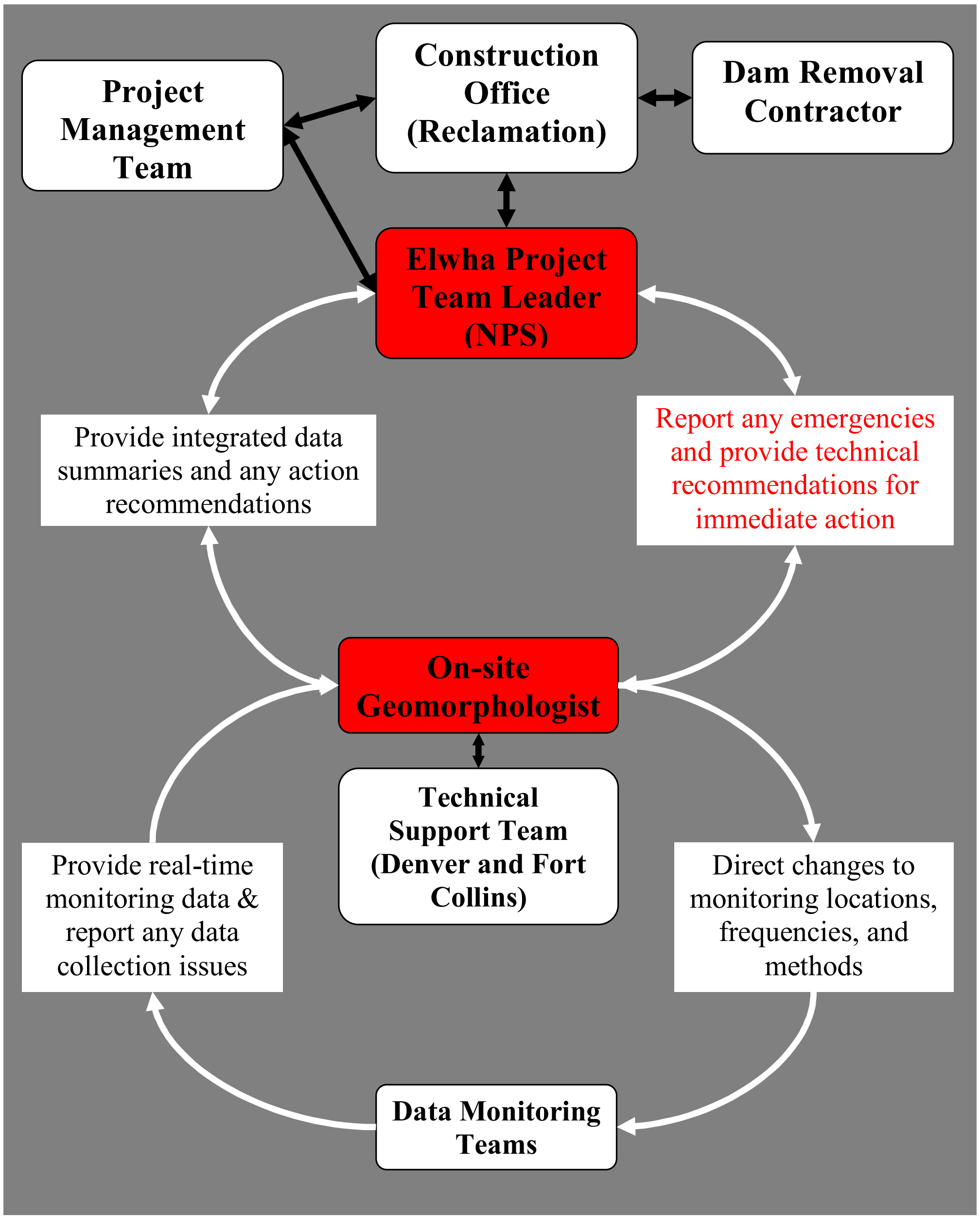

Figure 5. Adaptive management communication process.

The Project Management Team would be responsible for overall implementation of the Elwha Ecosystem Restoration Project, including the Adaptive Management Monitoring Program. The Project Management Team would be composed of managers from the National Park Service and the Bureau of Reclamation (Table 4). The Project Management Team would have the authority to implement adaptive management actions (see Section 4.4) in response to information and recommendations provided from the on-site Geomorphologist through the Olympic Elwha Project Team Leader. Any directives to the dam removal contractor would go through the Construction Office.

Table 4. Elwha Ecosystem Restoration Project Management Team

Agency	Office	Position or Group	Location
National Park Service	Olympic National Park	Park Superintendent	Port Angeles, WA
National Park Service	Olympic National Park	Olympic Elwha Project Team Leader	Port Angeles, WA
Bureau of Reclamation	Lower Columbia Area Office	Area Office Manager (LCA-1000)	Portland, OR
Bureau of Reclamation	Elwha Restoration Project Office	Project Manager (ELW-1000A)	Port Angeles, WA
Bureau of Reclamation	Pacific Northwest Regional Office	Deputy Regional Director (PN-1050)	Boise, ID
Bureau of Reclamation	Pacific Northwest Regional Office	Construction Engineer (NCO-3100)	Boise, ID
Bureau of Reclamation	Pacific Northwest Regional Office	Liaison & Coordination (PN-6309)	Boise, ID
Bureau of Reclamation	Technical Service Center	Manager, Waterways and Concrete Dams Group (8668130)	Denver, CO

The on-site Geomorphologist, with assistance from the technical support team, would be responsible for overseeing all data collection by the monitoring teams and would be responsible for the analysis and interpretation of all adaptive management monitoring data. In the event of any unanticipated sediment impacts from dam removal are discovered from the monitoring data, the on-site Geomorphologist would be charged with trying to determine what caused the impact, if the impact would likely continue in the future, and to provide any recommendations for management action to the Elwha Project Team Leader.

The Technical Support Team would be composed of staff from the Bureau of Reclamation, National Park Service, and Geological Survey with expertise in the areas of sediment transport, geomorphology, geology, groundwater, and stream gaging (Table 5).

Table 5. Adaptive Management Monitoring Technical Support Team				
Agency	**Office**	**Technical Group**	**Location**	**Specialty**
Bureau of Reclamation	Technical Service Center	Sedimentation and River Hydraulics Group	Denver, CO	Sediment processes
Bureau of Reclamation	Pacific Northwest Regional Office	Geology Group	Boise, ID	Geology
Bureau of Reclamation	Pacific Northwest Regional Office	River and Reservoir Operations	Grand Coulee, WA	Ground water
National Park Service	Water Resource Division	Water Operations Branch	Fort Collins, CO	Sediment processes
Geological Survey	Water Resource Division	Washington District	Tacoma, WA	Hydrologic data

Collection and basic processing of the adaptive management monitoring data would be conducted by the Data Monitoring Teams, consisting of technical specialists and technicians who collect the data. They also would be responsible for ensuring the data is collected and submitted at pre-established intervals and that the data are accurate and properly documented. In the event any problems arise with the data collection process, these groups would be responsible for informing the on-site Geomorphologist as quickly as possible with the extent of the problem and any suggested modifications or solutions. The processed monitoring data would then be disseminated as described in the next section.

4.2 Dissemination of Monitoring Information

The National Park Service Elwha Restoration Office in Port Angeles would be responsible for developing and managing a WEB accessible database to disseminate adaptive monitoring information and results. The WEB accessible database is expected to provide a fast and efficient means of transferring data among technical groups, project personnel, management, and other interested parties including the general public. Reports discussing interpretations and recommendations based on the adaptive management monitoring will also be posted to the WEB site after they have been reviewed by the Elwha Project Team Leader. The WEB site would also include links to past reports and general information about the Elwha River Restoration Project including the latest schedule for dam removal and reservoir drawdown.

Many categories of adaptive management monitoring data would be accessible through the WEB site on a nearly real-time, but provisional, basis, such as stream gage information and time-lapse photographs of the project site. The on-site geomorphologist would be responsible for ensuring that the real-time monitoring information, from the Data Monitoring Teams, is available for dissemination through the Project WEB site with links to other sites. The USGS would collect and store stream gage information such as river stage, discharge, temperature, turbidity, and suspended sediment concentration. The stream-gage data would be accessible through either the Project WEB site or USGS WEB site. Other data would be collected by Department of the Interior agencies, or their contractors, and would have to be processed by the Data Monitoring Teams prior to dissemination on the WEB page. Examples of this type of data include survey data of the reservoir and downstream river channel. Analyses of these data would be documented by the on-site Geomorphologist, with assistance from the Technical Support Team, and reported to the Elwha Project Team Leader. Analysis summaries would then be posted on the WEB site.

4.3 Key Reporting Times for Adaptive Management Monitoring Program

The on-site Geomorphologist is expected to have continual communication with the Elwha Project Team Leader. The key reporting events are listed in table 5. Initially prior to dam removal and in the first year of construction, the reporting events would be less frequent, but the frequency would increase as reservoir drawdown continued and as more of the dams are removed.

The on-site Geomorphologist will provide a summary of monitoring results, interpretations, future predictions, and recommendations, if any, to the Elwha Project Team Leader at the reporting events listed in Table 6 and at other times as conditions may warrant. Monitoring reports would be conveyed by e-mail, conference call, or in person depending on the nature and urgency of the monitoring results. The Elwha Project Team Leader and the Project Management Team would then make decisions regarding what, if any, adaptive management responses need to be implemented.

Table 6. Key reporting events by the on-site Geomorphologist to the Elwha Project Team Leader.

Reporting Interval	Dam Removal Process Steps
1	Initial conditions prior to dam removal
2	End of first winter flood season (March) after the beginning of dam removal
3	End of second winter flood season (March) after the beginning of dam removal
4	After each reservoir has been drawn down to the critical elevation (485 feet for Lake Mills and 140 feet for Lake Aldwell)
5	After the eroding delta from each reservoir has reached the dam
6	After each increment of reservoir drawdown at Lake Mills

The response time needed for the Project Management Team to make decisions regarding whether to implement adaptive management actions will vary depending on each unique situation. Emergency situations would require the most urgent response time. In some cases, the Elwha Project Team Leader may have to direct the Reclamation's Construction Office to take emergency actions.

Other, non-urgent situations may also require additional meetings between the Elwha Project Team Leader and the Project Management Team outside regularly planned intervals when unanticipated reservoir or river responses occur. For example, monitoring data may indicate the beginning of a problem that may eventually threaten property or infrastructure along the river corridor. Such a situation would require a special meeting to make a decision on how to address the problem.

4.4 Potential Adaptive Management Actions

Adaptive management actions that do not affect the Project schedule or budget would be implemented by the Elwha Project Team Leader and on-site Geomorphologist. Actions that would affect the Project schedule or budget first would be approved by the Project Management Team. Possible management actions that have been identified are listed below.

1. Modify monitoring methods, locations, or frequencies.
2. Adjust water treatment procedures within design range of the facilities (e.g. adjust the concentration or type of chemical flocculants).
3. Locally protect downstream infrastructure (including wells) and property.
4. Alter the rate of dam removal and reservoir drawdown.
5. Temporarily halt dam removal and reservoir drawdown.
6. Emergency evacuation.

The following paragraphs elaborate on each of these potential management actions and discuss the types of situations that might initiate them as a result of adaptive management monitoring data.

4.4.1 Modify Monitoring Data Collection

Intensive monitoring of sediment transport will begin in the reservoirs. Monitoring of the coarse sediment deposition along the downstream river channel will begin once the coarse delta sediments have reached the dams. The advancement of the first bed-load wave along the river channel will initiate the monitoring of river stage.

Increases in turbidity and suspended sediment concentration in the downstream river channel may require the dilution of river water samples or changes in instruments.

Adaptive management monitoring is intended to provide the basis for modifying the rate of dam removal, implementing downstream mitigation measures, and improving future predictions of physical responses to dam removal. Improved predictions will help provide early and accurate warning of potential problems. Therefore, adaptive management monitoring must produce information that is accurate, relevant, timely and spatially robust. Some monitoring results during dam removal may indicate that the collection of certain monitoring data can be scaled back or possibly eliminated. Unanticipated responses also may be observed, in which case additional monitoring parameters, locations, and frequencies may be required. Finally, some monitoring results may end up producing information that is either not timely or useful to project managers. In this case, monitoring methods, protocols or reporting standards may need to be modified.

4.4.2 Alter Water Treatment Techniques

Water treatment plants will provide water for municipal and industrial users both during and after dam removal. Water will be diverted from the Elwha Surface Water Intake structure located in the vicinity of the existing City of Port Angeles Diversion Structure. The diverted water will be initially treated at the Elwha Water Treatment Plant with a conventional coagulation and sedimentation process to remove excess sediments. Additional treatment of the water will occur at the Port Angeles Water Treatment Plant for municipal use and at the Nippon water treatment plant for industrial use. Water treatment plant operations may have to be adjusted, within design operation capabilities, as suspended sediment concentrations increase. For example, different chemical flocculants could be used to settle suspended sediment at a faster rate or chemicals could be used to treat iron and manganese. Dam removal will only be slowed or temporarily halted to reduce suspended sediment concentrations if the water treatment facilities are unable to adequately treat the water required by municipal or industrial water users.

4.4.3 Locally Protect Infrastructure and Property from Flooding and Bank Erosion

The physical process responses to dam removal on the Elwha River are not expected to cause widespread flooding and erosion of terrace banks along the outside edges of the flood plain. However, in localized situations, infrastructure or private property could be threatened by terrace bank erosion and flooding. Many of these situations will not require modifications to the dam removal program, but may require local mitigation such as streambank protection, modification or construction of levees, placement or relocation of large woody debris, or the maintenance of adequate fish passage. Levees and bank protection will be constructed prior to dam removal to protect property or infrastructure that could otherwise be impacted. To address unanticipated impacts, infrastructure and property will be the subjects of adaptive management monitoring. If necessary, monitoring results could trigger project management responses to protect infrastructure and property if the impacts are known to be caused by dam removal. In these cases, the on-site Geomorphologist would make recommendations to the Elwha Project Team Leader regarding what type of mitigation may be needed and how soon it may be needed. The decision of if and when to implement a mitigation project would be made by the Superintendent of Olympic National Park.

4.4.4 Alter the rate of dam removal

The rate of dam removal may be altered to accelerate or slow down the rate of delta erosion and redistribution in the reservoirs if the rate is unacceptable to achieve management objectives related to reservoir sediment. If the reservoir can be drawn down in advance of dam removal, then the it may be possible, depending on inflows, to adjust the drawdown increment to optimize the reservoir sediment erosion.

If a landslide were to occur during dam removal, an additional investigation would be conducted by a geologist to determine if the landslide was caused by dam removal, if additional landslides would be expected in the future, and if any adaptive management response were required. Although landslides are not expected, the occurrence of a landslide, as a result of reservoir drawdown, could mean that the continued rate of reservoir drawdown would have to be even slower until the receding reservoir is no longer in contact with the potential landslide area.

4.4.5 Temporarily Halt Reservoir Drawdown Prior to Reservoir Filling with Sediment

During dam removal and reservoir drawdown, suspended sediment concentrations are initially expected to be low and then increase with reservoir drawdown as more fine sediment is accessed by the eroding river channels and the suspended sediment is mixed with a receding reservoir. Maximum suspended sediment concentrations downstream from the two reservoirs are expected to be high (up to 50,000 ppm for durations of a few days). However, reservoir drawdown may have to be temporarily halted if the suspended sediment concentrations exceed the capabilities of the municipal and industrial water treatment facilities and there is limited or no water storage available to meet demand.

River flows discharged from the reservoir will temporarily increase during each increment of reservoir drawdown, but the increase is not expected to cause flooding. Downstream residents and the general public will be warned prior to these increases in river discharge. The rate of reservoir drawdown will have to be slowed if the downstream increases in river discharge are found to cause flooding problems for downstream residents or the general public. The reservoir drawdown rate will be slow enough that it is not anticipated to induce any landslides along the perimeter of either Lake Mills or Lake Aldwell (see section 4.4.4).

4.4.6 Temporarily Halt Dam Removal after the Reservoir Has Filled with Sediment

The reservoir storage capacity will reduce as each dam is removed and as eroding delta sediments fill in the remaining reservoir volume. After the eroding delta sediments have reached the remaining dam, the reservoir pool will no longer exist. After this condition has been reached, continued dam removal will result in the downstream release of coarse delta sediments in addition to the fine suspended sediments eroded from the reservoir bottoms. The rate at which coarse sediment is released from the reservoir will depend primarily on the rate of dam removal and the river flow through the reservoir. Since the dams will be removed during low to moderate flows, most of the coarse sediments will be eroded from the reservoirs during these same periods. Coarse sediments transported into the downstream river channel are predicted to deposit in pools, eddies, and other low-velocity environments, but are not predicted to deposit on hydraulic controls of the river such as rapids and riffles. Given this prediction, the river water surface elevations will not significantly change for a given river flow. However, if coarse sediment does unexpectedly deposit on riffles and rapids, the river water surface elevation upstream of these aggradational areas could result in a potential flood risk to nearby property. Excessive aggradation of the river channel could also induce bank erosion, lateral channel migration and meander-bend cutoffs. If monitoring activities detect that river-bed aggradation would increase the 100-year flood stage by more than 2 feet, then dam removal will have to be temporarily halted or slowed to allow time for the system to transport the sediment downstream (see section 5.4.1).

Coarse sediment is expected to erode from the reservoirs through head-cut erosion even during low-flow periods. This process will help the new channel achieve an equilibrium slope. However, if river flows are insufficient for the erosion to keep pace with dam removal, then too much coarse sediment would be left in the former reservoir and would be eroded at an uncontrolled rate after the dam has been removed. Therefore, dam removal will have to be temporarily halted or slowed if too little coarse sediment were eroded from the reservoir to allow the erosion to catch up with the pace of dam removal.

4.4.7 Emergency Evacuation Plan

One of the main objectives of the dam removal and sediment management plans is to carry out dam removal in a safe and efficient manner. The existing emergency preparedness plans for Glines Canyon and Elwha Dams (stored at Elwha Project Office) would be followed in the unlikely event of any of any large and unanticipated water release from either reservoir during dam removal.

5.0 PHYSICAL PROCESSES AND MONITORING STRATEGIES

Sedimentation processes (erosion, transport and deposition) and large woody debris loading will likely alter the physical structure of the stream channel, flood plain, and riparian zone. In addition, changes in water quality are expected that will alter aquatic habitat characteristics and will require water treatment for domestic and industrial purposes. Water treatment plants and levee improvements are being designed to prevent impacts to water users and property. Excessive sediment concentrations, turbidity, and channel aggradation would be undesirable and require corrective action during dam removal. The processes and conditions that could possibly require corrective action will be the subject of adaptive management monitoring.

Other processes and conditions are expected to occur and will be part of the natural evolution of the fluvial system to a new state of dynamic equilibrium. However, intensive intervention to directly manage physical processes is not anticipated and the role of restoration monitoring primarily will be to scientifically document physical processes and the natural response of the fluvial system to dam removal.

For the adaptive management monitoring, estimates are provided under each category in this section as to the frequency, duration, and locations of monitoring activities. Some tasks must be accomplished prior to the start of dam removal, some during the reservoir drawdown, some will not be initiated until the reservoir pool is essentially gone, and others may continue after dam removal is completed. The frequency of monitoring depends on the progression of sediment transport both in the reservoirs and in the downstream river channel. Certain monitoring activities would continue during floods to help protect downstream infrastructure, property, and residents.

The plan is to remove both dams concurrently within a 3-year time period. Based on sediment studies conducted for the EIS, high sediment loads in the downstream river channel are expected to continue for 3 years following the completion of dam removal (Randle et al, 1996). At this time, the remaining reservoir sediments are predicted to stabilize so that sediment concentrations or turbidity in the Elwha River are nearly the same downstream from the reservoirs as upstream from Lake Mills. Therefore, adaptive management monitoring activities discussed in this chapter are planned to cease approximately 3 years following the completion of dam removal. As a check on this prediction, criteria have been established to test whether significant sediment impacts are indeed over three years following dam removal (see Section 3.4 and Appendix B). If it is necessary to continue adaptive management monitoring activities for a longer timeframe, additional funds would be required beyond what is estimated in this plan.

The following sections briefly describe the specific physical processes and conditions that will be influenced by dam removal and ecosystem restoration, and discusses which of these will be the subjects of adaptive management monitoring and some initial ideas on potential subjects of restoration monitoring.

5.1 Reservoir Sediment Erosion and Redistribution

Adaptive Management
- Prior to dam removal
  - Lake Mills Survey
  - WEB camera installation
  - Advance drawdown
- During dam removal
  - Downstream delta progression
  - Release of coarse sediment
- After dam removal
- Criteria to discontinue adaptive management monitoring

Restoration Monitoring

By 1994, nearly 18 million yds^{3}of sediment had accumulated within the reservoirs formed behind Elwha and Glines Canyon Dams (Gilbert and Link, Reclamation, 1996). By 2008, the estimated sedimentation volume is expected to be about 22 million yds^3 (based on extrapolation of the average annual sediment deposition rate in delta) Over half of this reservoir sediment is silt- and clay-sized material that has deposited along the reservoir bottoms. The remaining sediment is sand and gravel-sized sediment deposited as delta formations at the head of each reservoir. About three-fourths of the total reservoir sedimentation is deposited within the upstream reservoir Lake Mills. When the reservoirs are drawn down during dam removal, the river will erode (through head-cut erosion) a portion of the reservoir sediment.

Fine-sized sediment (silt and clay) eroded from the reservoirs during the removal of Elwha and Glines Canyon Dams is expected to be quickly transported into the downstream river channel. As a result, suspended sediment concentrations and turbidities will be temporarily large during the erosion of reservoir sediment, but then decrease to natural levels that presently exist upstream from Lake Mills. The return to natural levels is predicted to occur within three years following the completion of the dam removals. Water treatment plants and new wells (delete?) are being constructed to mitigate the increase in suspended sediment concentration to existing water users. Within three to five years following the completion of dam removal, sediment impacts associated with dam removal are predicted to decrease to minimal levels. However, as long as significant sediment impacts still exist adaptive management activities such as operation of the water treatment plant and potential mitigation associated with unanticipated flooding or bank erosion will continue. In order to determine when sediment impacts downstream of the dams have decreased to negligible levels, certain monitoring activities will continue after dam removal is completed. It is planned to have these monitoring activities continue for three years following dam removal, but if unanticipated sediment impacts are still occurring monitoring would need to continue until the impacts can be deemed non-critical to water quality, flooding, or other safety issues that would require adaptive management actions (see Section 3.4 and Appendix B).

By drawing the reservoir down in controlled increments, the coarse-sized reservoir sediment (sand and gravel) is predicted to erode and redeposit within the reservoir during the initial phases of dam removal. During this process, the project objective is to have a substantial portion of the reservoir sediments form a series of terraces that will become re-vegetated and stabilize within the former reservoir areas (Randle et al., 1996). At the upstream end of the eroding delta, the lateral erosion is expected to be at a minimum and the erosion channel width is expected to be a function of river discharge. This is expected to result in one or more narrow, deep, and incised channels at the upstream end of the delta, but the channels are expected to be much wider downstream (Figure 6). Lateral erosion processes are predicted to be at their maximum where the eroding delta meets the receded reservoir.

During a 1994 Lake Mills drawdown experiment, the reservoir was lowered a total of # feet to learn about the delta erosion and redistribution processes. During the draw down the Elwha River was observed to initially flow along the upstream delta in three separate channels (Childers et al, 2000). As the reservoir drawdown continued, the two incising channels along the far left and right margins of the reservoir captured all the flow from entering the middle channel. Since the majority of the river water flowed down the far right channel, this channel would have been expected to eventually capture all the flow from left channel if the reservoir drawdown had continued. Very little lateral erosion was observed along these two channels crossing the upstream one-third of the delta during the 1994 Lake Mills drawdown experiment.

Each increment of reservoir drawdown will cause a new increment of delta erosion. During each drawdown increment, erosion channels will incise into the exposed reservoir sediments. From a sediment management perspective, the ideal scenario is to allow the erosion channels to migrate across the exposed delta surface until a new delta is deposited across the receded reservoir. This can be obtained by optimizing the amount of reservoir drawdown increment and the length of time at which the reservoir is subsequently held at a constant elevation. If the reservoir drawdown increment is too small, then the erosion channels will tend to armor and erosion will cease until the next reservoir drawdown increment or until a flood occurs. If the delta is actively eroding, but the reservoir is not held at a constant elevation for a long enough period, then the lateral erosion across the delta surface will cease and channel incision will resume. These processes could lead to an undesirable amount of high, unstable sediment terraces that could lead to uncontrolled large pulses of sediment erosion once the dams are removed. A physical model conducted in 200# tested a variety of reservoir drawdown increments to predict potential channel incision amounts and locations. The results from this study and geologic investigations of hillslope stability suggest that a reservoir drawdown increment of 2 ft/day would be ideal.

Figure 6. Lake Mills Delta during the 1994 Drawdown Experiment.

After the top half to two-thirds of the dam has been removed, the eroding and advancing coarse delta sediments that have reached the dam will completely fill the remaining reservoir with sediment (Randle et al., 1996). At this critical point in time, further dam removal will result in the downstream release of coarse sediments. Coarse delta sediments will be transported as bed-material load, some of which is expected to deposit along the downstream river channel in low-velocity environments such as pools, backwater channels, eddies (recirculation zones), and the flood plain. Over a period of several years following dam removal, most of the coarse sediments eroded from the reservoirs are predicted to be transported to the Strait of Juan de Fuca (Randle et al., 1996). The deposition of some coarse sediment may persist for decades and act to restore the pre-dam river channel alignment, gradient and planform that were altered as a result of the dams.

The erosion, redistribution, and stability of sediments within the former reservoirs are of major interest both to the dam removal process and to the long-term restoration of the fluvial system. Therefore, these processes are of interest to both the adaptive management and restoration monitoring programs. The amount of delta sediment erosion and redistribution between reservoir drawdown increments is of interest to the dam removal process. Once sediment has filled in the reservoir volume behind the remaining dam, subsequent erosion of coarse sediments will result in transport over the dam and into the downstream river channel. Therefore, the rates of reservoir sediment erosion and redistribution will be measured and compared to the predicted rates that were used to develop the dam removal schedule. A certain amount of reservoir sediment erosion and redistribution needs to occur prior to the draining of the reservoir pool in order to avoid excessive and uncontrolled release of coarse sediment from the remaining dam.

The extent and amount of reservoir sediment erosion and redistribution will also influence the long-term stability of the sediments remaining on the former lakebeds, including re-vegetation. Sediments remaining on the former lakebeds and near the new river channel will remain a source of sediment erosion following dam removal until natural flood plain development within the sediment terraces and re-vegetation of the terrace and flood plain surfaces are complete. The following sections describe the monitoring activities that will assist in tracking the erosion and redistribution of coarse reservoir sediments within the two reservoirs. Monitoring of suspended sediment levels and coarse-sized sediment transport through the downstream river channel is discussed in Sections 5.3 and 5.4, respectively.

5.1.1 Adaptive Management Monitoring

The adaptive management monitoring will provide important real-time feed back on the progress of the reservoir drawdown, delta erosion and downstream progression, and the release of coarse sediment from the reservoirs. A summary of adaptive management activities for reservoir sediment erosion and redistribution are listed in Table 6.

Table 6. Adaptive Management Monitoring for Reservoir Sediment Erosion and Redistribution

Measurement parameter	Location	Frequency	Duration
Initial bathymetric survey of Lake Mills	Lake Mills	Once	Prior to dam removal and the advance drawdown of Lake Mills
Reservoir water surface elevation	Lake Mills and Lake Aldwell	Manual measurements three times per day	During reservoir draw downs until the delta has reached the dam
Remote visual observations (WEB cameras)	4 WEB cameras at Lake Mills and 3 WEB cameras at Lake Aldwell	Continuous real-time monitoring	During reservoir draw downs and for three years following dam removal
Delta front position	Lake Mills and Lake Aldwell	Once per dam removal increment while the reservoir pool still exists (17 times in Lake Mills)	During reservoir draw downs until each delta has reached the dam
Topographic survey of the remaining reservoir sediment above and below water.	Lake Mills and Lake Aldwell	Once when each dam is removed to near the critical elevation	During dam removal
River erosion channel surveys	Lake Mills and Lake Aldwell	Once per dam removal increment after critical elevation is reached and twice per year after dam removal	During dam removal and for 3 years after dam removal
Geomorphic reach assessment of Lake Mills and Lake Aldwell	Lake Mills and Lake Aldwell	Once after dam removal to prove geomorphic stability	After dam removal

5.1.1.1 Lake Mills Resurvey

By 2008, about 4 million yds^3 of additional sediment are expected to deposit in Lake Mills since the last 1994 survey. Also, the previous 1994 survey was conducted in a local datum. Therefore, a new survey of Lake Mills in 1983 North American Datum (NAD), 1988 National Geodetic Vertical Datum (NGVD) will be conducted prior to the first reservoir drawdown to update the estimated sediment volume deposited in the reservoir. Lake Aldwell was also surveyed in 1994, but this reservoir is not expected to accumulate much sediment because most of the upstream sediment supply is trapped in Lake Mills. The intervening drainage area between the two dams (about 5 percent of the total drainage area) will still contribute some sediment.

5.1.1.2 Reservoir Water Surface Elevation

In order to track the progress of the reservoir drawdown, the water surface elevation of each reservoir will be manually monitored by the dam removal contractor and Reclamation inspectors at least three times per day. The staff gages will be installed and surveyed for these manual observations at each reservoir just prior to the start of the first reservoir drawdown.

Reservoir water surface elevations will tend to decrease rapidly after each dam removal increment and then become relatively constant until the next dam removal increment. However, water surface elevations will fluctuate with fluctuations in reservoir inflow. Because the reservoir shoreline will continue to recede during reservoir drawdown, the reservoir stage staff gage will have to be relocated several times as the dam is removed. Initially, the existing staff gage and stage recorder on each dam will be used. Eventually, the reservoirs will be drawn down enough that the existing staff gage and stage recorder will have to be extended and then relocated. Also, the structures that they are attached to will eventually be removed.

5.1.1.3 WEB Cameras

Because not everyone who is interested in monitoring the progress of dam removal and reservoir sediment erosion will always be on-site, WEB cameras will be used that can relay real-time photography through the Internet (Figure 7). The plan is to install WEB cameras overlooking each reservoir to continuously monitor the sediment erosion and redistribution during dam removal and the reservoir drawdown.

For Lake Mills, a camera tower (utility pole) would be constructed at the observation point along the Olympic Hot Springs Road, south of Lake Mills. From this camera tower, one WEB camera (#1) will be installed to monitor most of Lake Mills. This site tends to provide an aerial view because it is several hundred feet above the reservoir, but this site will be occasionally affected by fog. A WEB camera (#2) will also be installed along the upstream portion of the reservoir margin to overlook the present delta and another WEB camera (#3) will be installed near the dam tender’s house to overlook the lower portion of Lake Mills. In addition, a WEB camera (#4) will be installed downstream of the dam along the right abutment to monitor the removal of Glines Canyon Dam (“dam cam”).

For Lake Aldwell, the plan is to install one WEB camera (#1) and tower along Highway 101 to overlook the upstream portion of the reservoir. The plan is to install another WEB camera (#2) near the left abutment of Elwha Dam to overlook the downstream portion of Lake Aldwell. A WEB camera (#3) would also be installed along the transmission line and near the Elwha Dam access road to overlook the removal of Elwha Dam.

Figure 7. Possible WEB camera views.

5.1.1.4 Advance Draw Downs of Lake Mills Prior to Dam Removal

To learn more about the sediment re-distribution processes, a physical model of the Lake Mills reservoir drawdown and sediment erosion processes was conducted at the University of Minnesota, St. Anthony Falls Laboratory (Bromley, et al, 2003). The results from this model indicate the timing and incremental amounts of dam removal have a significant influence on the rate and extent of delta erosion and redistribution. The physical modeling also indicated that there is a potential risk that the river channel could be captured on one side of the reservoir or the other and incise to a degree that delta reworking is no longer feasible. If this incised channel were to remain in place, large, unstable sediment banks could persist that would make it difficult to manage the downstream progression of sediment. The objective of the advance drawdown is to maximize the amount of lateral delta erosion and re-deposition of delta sediments across the receding reservoir prior to the start of dam removal. To accomplish this, the erosion channels will be allowed to form and then managed, if necessary, to prevent one channel from incising to the point that delta sweeping no longer occurs.

Lake Mills will be partially drawn down two times prior to the start of dam removal. The initial drawdown would occur during the spring and summer prior to the start of the removal of Glines Canyon Dam and prior to the completion of the downstream water treatment plants. The total amount of advance reservoir drawdown is expected to be 18 feet for the first drawdown and between 50 to 70 feet for the second drawdown.

For the first 18 feet of the initial drawdown, the reservoir would be lowered using the existing spillway gates at a rate of 2 feet per day until the inflowing river channel is actively incising the delta (?). After 18 feet of drawdown, the reservoir level would be held constant until the eroding delta sediment had deposited across the entire width of the receded reservoir. This approach is based on the process that was observed during the 1994 drawdown experiment (Childers and others, 2000) and during recent physical modeling of the Lake Mills drawdown. The amount of the reservoir drawdown increment (2 ft/day) would be increased if the delta erosion process began to slow down or stop (perhaps due to armoring) so that there wouldn't be enough sediment to redeposit across the width of the reservoir. The next increment of reservoir drawdown would begin as soon the delta had formed across the reservoir width (based on WEB camera or field observations). After the initial 18 feet of drawdown is accomplished, the power penstock would be utilized to further draw down the reservoir in increments of 10 to 15 ft (at 2 ft/day and then held constant after each one? Didn't Tom have a schedule of these drawdowns and hold periods in between?).

Lake Mills would be expected to refill during the subsequent winter flood season before the beginning of dam removal. Just before dam removal, the reservoir would be drawn down a second (and final) time to the level achieved during the first advance drawdown elevation in the previous year (50 to 70 feet). The same drawdown increments and outlet works would be utilized as in the first drawdown (?). Dam removal above the drawn down reservoir elevation could then proceed at a rapid pace, and without regard to sediment management since the sediment would have already been redistributed within the reservoir. Subsequent dam removal would then follow the controlled increments of dam removal linked to sediment management (see Section 5.1.1.5).

During the initial two reservoir draw downs, the total amount of drawdown achieved could be limited if either of the following two criteria were met:

1. Reservoir inflow exceeds the outlet capacity of Glines Canyon Dam. This could occur because of increased reservoir inflows or because the outlet capacity will decrease as the lake is drawn down. The outlet capacity will increase if the powerplant is decommissioned prior to the advance drawdown. In the case of increased inflows, reservoir drawdown could resume once the inflows had decreased.
2. Elwha River turbidity downstream from Elwha Dam exceeds the treatment capability of downstream water users. Downstream turbidity would be continuously monitored at the surface water diversion structure. Reservoir drawdown would be slowed or halted if turbidity were getting close to the treatment limit. Would it then be resumed?

5.1.1.5 Drawdown of Lake Mills during Dam Removal

The first 50 to 70 feet of reservoir drawdown will have occurred prior to the start of dam removal, such that additional reservoir drawdown is not needed until the point at which the dam has been removed down to the lowered reservoir elevation. Once the dam has been removed down to the lowered reservoir elevation, the additional # feet of reservoir drawdown will occur in controlled increments. During this next phase, the reservoir sediments will be ready for a new increment of reservoir drawdown once a new delta has deposited across the receded reservoir or if the erosion process has ceased due to armoring. As long as the delta continues to actively erode, the next increment of reservoir drawdown will not be allowed until a new delta has deposited across the receded reservoir or until a period of at least 14 days has passed since the last reservoir drawdown increment, whichever comes first. A 14-day period was chosen based on experience from the 1994 Lake Mills drawdown test (Childers et al, 2000), physical model experiments, and schedule requirements for removal of Glines Canyon Dam (Hepler and Scott, 1996). The 14-day period should allow enough time for the new delta to deposit across the reservoir if the exposed delta is actively eroding.

Even if the pace of dam removal exceeds the rate of reservoir sediment erosion, the reservoir sediments can still be contained within the reservoir as long as the dam is not removed below the critical elevation. Additionally, the temporary halt to dam removal and reservoir drawdown during fish windows (especially when flows are high) is expected to allow the reservoir sediment erosion to catch up, if necessary, with the rate of dam removal. Suspended sediment in the downstream river channel may remain at elevated levels for a certain period of time following the last dam removal increment. In addition, suspended sediment concentrations could increase during fish window periods that occur during snowmelt runoff or the winter flood season when concentrations will naturally increase within the watershed.

Do these tasks all move up to advance drawdown now?
A few days prior to the next drawdown increment, the position of the advancing delta front will be monitored once per drawdown increment from a boat using a hand-held G.P.S. instrument to trace the shallow edge of the new delta surface. It may also be possible to monitor the position of the delta front using the WEB camera photos, but this method may be unreliable when visibility is poor due to rain or fog. Successive positions of the delta front will then be plotted, using G.I.S., on the most recent ortho-rectified aerial photograph (presently the year 2005). The amount of sediment remaining above the elevation of the river-erosion channels will be visually estimated at the same time the position of the delta front is measured. The successive positions of the delta front and the corresponding visual estimates of the remaining reservoir sediment will be used to monitor the progress of the sediment erosion and redistribution.

Comment [BoR1]: Joe's comment is visual estimate seems vague for someone else to implement. Can we say a % volume or give any guidelines?

The longitudinal slope of the main river-erosion channel within each reservoir will also be estimated once per reservoir drawdown increment a few days prior to the next drawdown increment. The slope estimate could be determined by the longitudinal delta position and lake elevation at the downstream end, and a survey of the erosion channel elevation at the upstream end. Repeated longitudinal slope measurements of the river-erosion channels will document any increasing trends in the erosion slope and help determine the equilibrium slope within the reservoir area.

Additionally, evidence of armoring of the erosion channels across the exposed delta surface will be visually monitored during each reservoir drawdown increment. A condition of armoring in the erosion channel would be assumed when the channel bottom consists of coarse gravel or cobble that can be clearly seen through the flowing water, and there is no evidence of active lateral migration across the exposed delta. The presence of armoring indicates that the erosion channels will not migrate across the exposed delta until the next drawdown increment or flood.

5.1.1.6 Reservoir Monitoring Activities Just Prior to Downstream Release of Coarse Sediment

As long as each dam is not removed below a certain critical elevation (485 ft for Lake Mills and 140 ft for Lake Aldwell), the remaining reservoir pool can contain all of the delta sediments that could potentially be eroded. After the dam is removed beyond this critical elevation, the rate at which delta sediment is released to the downstream river channel depends on the rate of dam removal and the river discharge. When each dam is removed to near the critical elevation, a new topographic survey would be conducted to measure the volume of sediment that has re-deposited in the remaining reservoir pool and the volume of sediment that has not eroded above the receded reservoir. A boat equipped with a G.P.S. instrument and depth sounder will be used to survey the remaining reservoir pool. G.P.S. instruments or Lidar will be used to survey the topography of the exposed reservoir sediments (including terraces). The alignment, longitudinal slope, and width of the erosion channels will also be surveyed. For both reservoirs, the data from these surveys will be used to determine if the reservoir sediment erosion and redistribution has kept pace with dam removal. This will be primarily determined from assessing the longitudinal slope stability of the river erosion channels within each reservoir. If the longitudinal slope of the primary erosion channel is determined to be so steep that vertical incision is actively continuing, then dam removal would be halted until the slope became stable.

After the reservoir pool has filled in with the eroding sediment, the sediment erosion process will be driven by head-cut erosion. The upstream erosion channels in the former reservoir are predicted to first deepen and then widen. Channel widening will then migrate upstream, possibly resulting in an over-widened channel. The lateral erosion will occur along the erosion channel as the banks become over steepened and as channel migration and meandering occur. However, the eroding sediments will spill over the remaining dam crest rather than redepositing across the width of the reservoir.

Comment [BoR2]: Joe is wondering if physical model showed this and if so we should cite

This seems like it should go up with reservoir monitoring during drawdown?
The width, alignment, and longitudinal slope of the primary erosion channel and the bank heights will be measured at least once per dam removal increment using G.P.S. instruments. After dam removal, these measurements will continue once per quarter for an additional three years. If the river erosion channel becomes too narrow, too deep, and longitudinally too steep, then the rate that sediment is being eroded from the reservoir could begin to significantly exceed the transport capacity of the downstream river channel and cause excessive riverbed aggradation. The ideal width, depth, and slope is one that results in a sediment transport capacity equal to the sediment transport capacity of the downstream river channel. The rate of sediment erosion from the reservoir is expected to be greatest immediately after each increment of dam is removed and this rate is expected to decrease at an exponential rate until the next dam removal increment, assuming that the reservoir inflow remains constant.

Comment [BoR3]: Should we specify X # of XS's will be measured or spacing between sections? This could be really difficult if flows are high and channel is deep

Comment [BoR4]: Since reservoir inflow isn't constant Joe suggests changing this statement. What could happen during floods? Will this be monitored in both reservoir and d/s channel?

The average channel width of the downstream river is about 200 ft. The average river slope from the Altaire Bridge downstream to Lake Aldwell is 0.073 ft/ft. The average river slope downstream from Elwha Dam ranges from 0.0036 to 0.0039 ft/ft. If the erosion channels through the reservoir sediment evolve to have a sediment transport capacity significantly greater than the lower river, continued dam removal may have to be slowed or delayed until the sediment transport rate of the erosion channels reduces to the capacity of the downstream river channel. The sediment transport capacity of the reservoir erosion channel will be mathematically computed and compared with the computed capacity of downstream river channel. The sediment transport capacities will be computed from the measured channel geometry, longitudinal slope, and median particle size of the reservoir sediment, assuming normal depth and using the Yang sediment transport equations for sand (1973) and gravel (1984). If the computed sediment transport capacity in the reservoir erosion channel exceeds the transport capacity in the downstream river channel <u>and</u> significant aggradation is measured in the downstream river channel, then the rate of dam removal would be slowed or temporarily halted until the sediment transport of the reservoir erosion channel reduced. Significant aggradation of the downstream river channel is defined such that the 100-year flood stage would increase by at least 1.0 foot in the middle reach or 2.0 feet in the lower reach of the Elwha River.

Comment [BoR5]: Joe wants to know wht will be the hydraulic parameters (ie discharge) and if capacity of d/s channel varies by location which location(s) will we choose? Will we have a range to represent low, avg, high?

5.1.2 Restoration Monitoring

Restoration monitoring of the reservoir sediment erosion and redistribution could answer many questions that are of interest to the Elwha River Restoration Project and to other potential dam removal projects. Such questions include:

- What portion of the reservoir sediment erodes from the reservoir?
- What are the plan form evolution changes that develop in the reservoir areas both during and after the dam removal?
- What are the concentrations of suspended sediment in the reservoir during dam removal?
- How well is fine suspended sediment mixed within the reservoir pool?
- What portion of the suspended sediment settles to the bottom of the reservoir and how does this portion change over time?
- What are the sediment erosion rates from the reservoir during and after dam removal?
- Do anaerobic conditions exist that create odor problems?
- How rapidly do flood plains develop (width and other geomorphic characteristics) as a function of annual peak discharge and vegetation reestablishment?
- How long does it take for the remaining reservoir sediment to become stable?
- How many sediment terraces form and how many of these terraces remain at a stable slope such that high rates of erosion are limited?
- How much sheet, rill, and gully erosion of delta terraces occurs?

The restoration monitoring that is necessary to answer these questions will be determined from individual through requests for proposals. Based on the 1994 Lake Mills Drawdown Experiment (Childers et al., 2000) the following measurements should work well to answer many of the restoration questions.

- Measure repeat cross-section surveys of the reservoir delta and lakebed.
- Evaluate time-lapsed photography from WEB cameras.
- Measure suspended sediment concentrations throughout the reservoir area and at various depths.
- Measure bedload and suspended load in the reservoir erosion channel, especially after the eroding delta sediments have advanced to the dam.

- Periodically sample the sediment and measure the concentrations of contaminants and other water quality parameters.
- Measure the evolution of sheet, rill and gully erosion of the exposed reservoir sediments.
- Establish the causes of surface erosion of reservoir sediments (e.g., surface runoff generated by exceedance of infiltration capacities; subsurface seepage; upslope hillslope runoff).
- Identify the species of vegetation growing on the exposed reservoir sediments. Establish vegetation plots and measure plant density and growth rates.
- Correlate vegetation establishment with expected reductions in surface (sheet, rill and gully) erosion of reservoir sediments.
- Measure the change through time of armor and sub-armor layer development in the erosion channels to aid with the interpretation of longitudinal profile and channel planform evolution.

5.2 Hillslope Stability

Rapid reservoir drawdown is known to initiate hillslope mass failures (landslides) under certain geologic and soil conditions. Drawdown-induced landslides are most common where soils are naturally unstable and when drawdown rates exceed the rate at which hillslope soils can drain ground water and bank storage from the reservoir. A large landslide into a reservoir could create a large water wave that could overtop the dam and result in a devastating, downstream flood wave. A landslide might also create sediment supply conditions or landscape features that will need to be stabilized before reservoir drawdown could continue. A reservoir landslide inventory and assessment was completed by Reclamation in 2002 (Burt, 2003).

In addition, river channel migration or avulsions, as a result of dam removal, may initiate or accelerate erosion at the toe of a steep slope and cause a landslide to occur. Landslide movements in high hazard areas of the reservoirs or downstream river valley are the subjects of adaptive management monitoring. The impact of landslides on long-term restoration progress in the reservoirs will be the subject of restoration monitoring.

5.2.1 Adaptive Management Monitoring

The latest reservoir landslide inspection was conducted in 2002 (Burt, 2003). A second analysis of reservoir landslide stability is presently being conducted to verify that a reservoir drawdown rate of 2 feet per day will have a low risk of inducing landslides (Young, in progress). Reservoir landslides would be visually inspected one additional time just prior to dam removal. Since the existing reservoir landslides appear to be shallow, the consequence of a landslide is not expected to affect the progress of dam removal. All potential landslide areas of the reservoirs and river channels will be visually monitored for slope stability by project personnel (Table 7). For Lake Mills and Lake Aldwell, areas will be visually monitored at least once per drawdown increment as long as a potential landslide is still inundated by a portion of the reservoir pool. This would occur by boat at the same time the delta is being surveyed.

For the downstream river channel, rates of channel migration are expected to increase during, and for a few years after, dam removal. Therefore, periodic monitoring by project personnel of at least one potential landslide area along the Elwha River (downstream from the Historic Ranger District) will begin after coarse delta sediments have been eroded from Lake Mills. This monitoring will continue throughout the dam removal process and for 3 years following dam removal. If additional erosion sites along the river develop during dam removal, monitoring of these areas would need to be incorporated by project personnel, particularly near areas of residential or industrial infrastructure.

If a landslide were to occur during dam removal, an additional investigation would be conducted by a geologist to determine if the landslide was caused by dam removal, if additional landslides would be expected in the future, and if any adaptive management response were required. This effort would be directed by the Project Management Team with assistance from the Techncial Team as needed. Although unexpected, if a landslide occurs as a result of reservoir drawdown, then the rate of continued reservoir drawdown could be slowed until the receding reservoir is no longer in contact with the potential landslide area. If monitoring detects an area of major slope instability along the downstream river channel, then appropriate measures will need to be done. Mitigation could include installation or modification to bank protection structures or installation of river deflection structures consisting of rock and/or large woody debris.

Table 7. Adaptive Management Monitoring for Reservoir and River Hillslope Stability

Measurement parameter	Number of Sites	Frequency	Duration
Lake Mills & Lake Aldwell Hillslope stability	11	Once	Just Prior to Dam Removal
Lake Mills & Lake Aldwell Hillslope stability	11	Once per drawdown increment during delta inspection	During Dam Removal Reservoir Drawdown Period
River Hillslope Stability	1	Periodically	During Dam Removal and for 3 years following

5.2.2 Restoration Monitoring

A restoration monitoring objective related to landslides induced by reservoir drawdown could be to evaluate their impact on long-term restoration progress in the reservoirs. However, landslides are not anticipated to occur as a result of reservoir drawdown so this topic of restoration monitoring has a lower priority relative to other categories of monitoring.

5.3 Water Quality (Turbidity and Suspended Sediment Transport)

Suspended sediment concentration is expected to be the primary water quality constituent affected by dam removal and restoration of the fluvial system. However, other water quality variables are also of concern, both to the domestic and industrial users, and to the river ecosystem. Iron concentrations may be an issue affecting sediment-settling rates in the water treatment facilities. Total organic carbon levels and stream temperatures will affect fisheries. Water quality constituents affecting water treatment for municipal and industrial purposes will be monitored by the water treatment facility and will not be the subject of this monitoring plan. At this point, water quality constituents other than suspended sediment are not likely to affect the dam removal process. Over the long term, monitoring the water quality aspects of aquatic habitat (especially temperature and aquatic macro invertebrates) are potential subjects of restoration monitoring.

As a new river channel is re-established on the former reservoir bed, silt and clay-sized sediments will be readily transported in suspension once they have been eroded by stream flow. The rate at which fine sediments are accessed by stream flow will primarily depend on the rate of dam removal, the width of the erosion channel, and the depth and velocity of river flow. Under natural conditions in a river, the river flow depth, width, velocity, and sediment concentration will all tend to increase with river flow. However during dam removal sediment concentrations are expected to be greatest during low-flow periods. This is because head-cut erosion will be occurring in the reservoir erosion channel as the dam is being removed during low flow periods. Mass wasting of river banks will also be a key contributor to high levels of suspended sediment during low flows as the reservoir is continually drawn down.

During the first phases of reservoir drawdown, the reservoir will still be large so that river erosion will be limited to the delta, which has a very low percentage of fine sediment. Suspended sediment concentrations will be low during this time because any fine sediment that is eroded will be diluted by the large reservoir. However, sediment concentrations will increase with continued reservoir drawdown because more fine sediment will be exposed to river erosion and the reservoir volume will continue to decrease. Eventually, enough of the dam will be removed so that the remaining reservoir is full of sediment. More of the fine sediment will be exposed to river erosion, especially during the last stages of dam removal and there will be no reservoir to dilute the concentrations. Peak sediment concentrations during some periods of dam removal are expected to reach tens of thousands of parts per million (10^4 ppm). Dam removal will temporarily halt during high-flow periods and the concentration of suspended sediment will tend to be diluted by the higher flow.

Comment [BoR6]: Joe wants to know how this compares to historic levels or levels following mt st Helens eruption in Toutle. He notes that 10^4 seems higher than potential water treatment capability. What is the design max capability?

High sediment concentrations have implications both to water treatment for domestic and municipal supplies, and to water quality for fisheries restoration. There may also be some water quality concerns related to near-shore marine environments. In particular, the ability to refine predictions of future suspended sediment concentrations will be important input to both the dam removal process and to water treatment activities during dam removal. This would be accomplished by correlating monitoring data of the reservoir sediment erosion with the real-time suspended sediment concentration data. Over the long term, measured suspended-sediment concentrations will help characterize the stabilization of erosion channels and will help define future water quality regimes for downstream uses. Therefore, suspended sediment concentrations will be the subjects of both adaptive management and restoration monitoring.

5.3.1 Adaptive Management Monitoring

Suspended sediment concentrations in the river must be managed such that the concentrations entering the municipal and industrial water treatment plants do not exceed their treatment capabilities. Water treatment plants and wells will be providing water for the following municipal and industrial users:

- City of Port Angeles
- Nippon Paper Industries (formerly Daishowa)
- Washington Department of Fish and Wildlife fish rearing channel
- Lower Elwha Klallam Tribe fish hatchery
- Elwha Place Homeowners Association
- Dry Creek Water Association

The continuous measurement of suspended sediment concentrations (or turbidity) will also be used to determine if concentrations (or turbidity) are reducing during fish windows.

Real time and continuous measurements of flow rate, suspended sediment concentration, and turbidity are needed along the Elwha River at the following locations:

- Upstream from Lake Mills at Goblins Gate (RM 17.5)
- Downstream from Glines Canyon Dam at the existing USGS gage near McDonald Bridge (RM 8.7)
- Downstream from Elwha Dam between the mouth of the canyon (RM 4.3) and the single-lane bridge on Elwha River Road (RM 3.2)

Stream gaging stations will have to be established in support of these measurements. To obtain experience with existing conditions, these measurements will be obtained over a wide range of flow conditions (preferably one year) prior to dam removal. During dam removal, the concentration and turbidity measured at the gage upstream from Lake Mills will be used to compute the concentration and turbidity downstream from Elwha Dam for the condition with both dams still in place. This information will be used to judge the performance of the City of Port Angeles water treatment facility.

Continuous suspended sediment concentrations will be directly measured using new technologies such as acoustic or light refraction instruments, or will be developed from an empirical relationship with turbidity. One possible method would be to install a streamside instrument (such as a LISST developed by Sequoia Scientific, Inc.) that would obtain samples from the river using a pump and continuously measure suspended sediment concentration and the particle size distribution in real time. The streamside installation would protect the instrument from large woody debris and allow the samples to be diluted so that higher concentrations can be measured.

Traditional depth-integrated suspended sediment samples could also be obtained across the entire river channel. This data would be used to determine the correlation between the average suspended sediment concentration across the entire river channel and the concentration measured by the streamside instrument from a single point. Such a correlation could be developed prior to dam removal and updated during the first year of dam removal.

Another possible application of real-time instrument would be in association with the treatment plant operation. Here it would most likely be used as a laboratory instrument. In this case, manually diluted samples would provide near instantaneous measures of suspended sediment concentration and particle size distribution. This real-time data would help to increase the operational efficiency of the water treatment plant.

An adaptive management response to handle higher than predicted suspended sediment loads entering the water treatment plant would be to modify operations (within the plant design capabilities) so dam removal could continue as planned. If the suspended sediment concentrations that enter the water treatment plants exceed the treatment capabilities then reservoir drawdown and dam removal will have to be temporarily halted until concentrations reduce to treatable levels.

Comment [BoR7]: What is treatable level?

A summary of adaptive management activities for water quality are listed in Table 8.

Table 8. Summary of Adaptive Management Monitoring Activities for Water Quality (Turbidity and Suspended Sediment Transport)		
Elwha River stream gaging above Lake Mills. The original site was at entrance to Rica Canyon which got destroyed in October 2003 flood. New site located near the canyon mouth.		
Measurement parameter	**Frequency**	**Duration**
Periodic discharge measurements and continuous river stage	Continuous real-time monitoring	during dam removal, and 3 years after dam removal
Suspended sediment concentration and particle grain size	Continuous real-time monitoring	during dam removal, and 3 years after dam removal
Turbidity	Continuous real-time monitoring	during dam removal, and 3 years after dam removal
Elwha River stream gaging at McDonald Bridge: USGS Station No. 12045500		
Measurement parameter	**Frequency**	**Duration**
Periodic discharge measurements and continuous river stage	Continuous real-time monitoring	during dam removal, and 3 years after dam removal
Suspended sediment concentration and particle grain size	Continuous real-time monitoring	during dam removal, and 3 years after dam removal
Turbidity	Continuous real-time monitoring	during dam removal, and 3 years after dam removal
Elwha River stream gaging Below Elwha Dam. The current site is located at the entrance to the municipal water-supply diversion tunnel. The plan is to remove and reinstall the turbidity sensor after the new diversion structure is complete.		
Measurement parameter	**Frequency**	**Duration**
Periodic discharge measurements and continuous river stage	Continuous real-time monitoring	during dam removal, and 3 years after dam removal

Suspended sediment concentration and particle grain size	Continuous real-time monitoring	during dam removal, and 3 years after dam removal
Turbidity	Continuous real-time monitoring	during dam removal, and 3 years after dam removal

Water quality monitoring will also occur inside the Elwha Water Treatment Plant (EWTP) as described in Table 9. Monitoring will include process operational monitoring and the permit compliance monitoring. The operational monitoring will be used to assess plant performance and the permit compliance monitoring will provide necessary records to satisfy the requirements of the NPDES permit for the discharge of residual solids.

Table 9. Water quality monitoring parameters planned for EWTP.

Category	Parameter	Type	Sample Location	Units	Frequency
River	Flow	Operational	Upstream gauging Station	cfs	Continuous
"	Turbidity	Operational	"	NTU	Continuous
Influent	Flow	Operational	Influent Pump Station	mgd	Continuous
"	Turbidity	Operational	"	NTU	Continuous
"	Temperature	Operational	"	degree F	Continuous
"	pH	Operational	"	SU	Continuous
"	TSS	Operational	"	mg/L	Daily
Chemical Feed (various)	Dose	Operational	Chemical Feed Pumps	mg/L	Continuous
Treated Water	Flow	Operational	Clearwell	mgd	Continuous
"	Turbidity	Operational	"	NTU	Continuous
"	Temperature	Operational	"	degree F	Continuous
"	pH	Operational	"	SU	Continuous
Residual Solids	Flow	Compliance	Solids Discharge Pipeline	mgd	Continuous
"	Temperature	Compliance	"	degree F	Continuous
"	pH	Compliance	"	SU	Continuous
"	Total Solids	Compliance	"	%	Daily

5.3.2 Restoration Monitoring

In addition to measurements of suspended sediment concentration and turbidity, other water quality parameters would be the subject of restoration monitoring. These other water quality parameters include dissolved oxygen, temperature, PH, nutrient loading, and organic chlorines (indicators of herbicides and pesticides).

5.4 Riverbed Aggradation and Flood Stage

Once the reservoir pools are completely filled with sediment, subsequent dam removal will result in the release of coarse reservoir delta sediments (sand-, gravel-, and cobble-size sediment). It is hypothesized that coarse sediment releases will proceed downstream as non-uniform waves of bedload. The maximum deposition height of each wave will be at its downstream front. These bedload waves will tend to move downstream at a speed much slower than the river flow. In reaches of low sediment transport capacity, these waves could superimpose and result in aggradation of the riverbed. Additionally, coarse bed sediments will locally deposit in low-velocity areas of the channel such as pools, point bars, channel margins, backwaters, eddies, flood plains, and the delta at the river mouth. Some of these deposits such as point bars, and flood plains may persist over the long term while other deposits may be temporary. For example, river pools may fill with coarse sediment during low-flow periods, but experience local scour during floods. Coarse sediment may tend to deposit in eddies during both high and low flows, but the eddy boundaries will tend to expand and then shrink with the passage of floods.

Several short- and long-term consequences of riverbed aggradation may be significant to this project. Riverbed aggradation may increase the rate of channel migration and change the channel plan form from a meandering to braided planform. The composition of the existing riverbed and delta material will change as sand and gravel are added to the armored downstream river channel. In addition, reach-scale aggradation could increase flood stage elevations (especially if deposition occurs at riffles and rapids and the aggradation levels are sustained during subsequent floods). Flood elevations could increase because bank-full capacities are reduced by bar deposits and log jams or by more uniform deposition along the channel bed. Furthermore, while local deposition in pools and channel margins may not significantly affect flood stage, riverbed aggradation at riffles, rapids, and other hydraulic controls of the river will increase flood stage. Riverbed aggradation and flood stage at locations vulnerable to increased flooding are potential subjects of adaptive management and restoration monitoring. In addition, channel geometry and the downstream progression of any bedload waves are potential subjects of both adaptive management monitoring and restoration monitoring.

5.4.1 Adaptive Management Monitoring

The adaptive management monitoring of riverbed aggradation and flood stage will consist of bed material size measurements, river water surface elevations, and channel geometry at several river cross sections (Table 10). Bed material size will be measured to determine if reservoir sediment has yet reached a certain cross section. This will also help monitor the downstream progress of the bedload wave. The water surface elevation will be measured to determine if there has been an increase due to riverbed aggradation. The river cross sections along with a longitudinal river profile (riverbed and water surface) will be surveyed at least twice per year during dam removal and once per year for three years after dam removal. However, if significant riverbed

Comment [BoR8]: Observed?

Comment [BoR9]: Joe wondering if only 1 wave is expected or several? More than one mentioned in previous section.

aggradation is detected, then the channel geometry will be measured more frequently to determine the depth and rate of aggradation.

Comment [BoR10]: When would automatic 2 surveys occur? IF aggradation, we only have budget for 1 more set of sections per year. .Does this work?

Table 10. Summary of Adaptive Management Monitoring Activities for Riverbed Aggradation and Flooding

Measurement parameter	Number of Sites	Frequency	Duration
Bed-material	20	Assume 12 sets of measurements (8 cross sections per set). The timing of each set depends on speed of bed-load sediment wave	After coarse sediments have been eroded from either dam until first bed-load wave reaches the mouth
Establish monitoring cross section and staff gage locations	20 (Measurements will also be made by USGS at 2 gaging stations)	Once	First year of dam removal
River Stage	20 (Measurements will also be made by USGS at 2 gaging stations)	Continuous at 6 sites, manually once per week at all sites once the first bed-load wave arrives, once per month at each site after dam removal.	Starting when first bed-load wave arrives and continued until 3 years after dam removal
Channel geometry (cross section surveys)	20 (Measurements will also be made by USGS at 2 gaging stations)	Three times during dam removal; once per year after dam removal	During dam removal and for 3 years after dam removal
Longitudinal channel profile	Entire river downstream of each dam	Three times during dam removal; once per year after dam removal	During dam removal and for 3 years after dam removal

Comment [BoR12]: Joe wants to know timing of these sections, what months of year.

Comment [BoR11]: Change this to 22 XS to match next table and be more clear rather than break out that 2 will be gaging sites;

Measurements will be made at the river cross sections listed in Table 11. The location of these cross sections is shown on aerial photographs in Appendix A. Cross section locations were chosen based on areas prone to existing flood risk or bank erosion. Aggradation and woody debris within the lower river reaches near the mouth of the Elwha River may result in braided, obstructed channels that are difficult to navigate by boat. If it is not possible to conduct a longitudinal survey through this lower river reach, survey data would be collected only at the monitoring cross sections. If a monitoring cross section is not accessible for any reason, the location would have to be adjusted and the survey results compared to previous longitudinal survey elevations (rather than previous cross section data).

Table 10. River Cross Section and Bank Erosion Monitoring Locations

Number	River Mile[1]	Location Description	Continuous Stage Recorder
1	12.612	Downstream side of Altaire Bridge	
2	12.422	Altaire Campground boat ramp	
3	12.137	Historic Ranger District	Yes
4	10.930	Natural channel constriction downstream from Elwha Campground	
5	9.928	Just upstream from the Olympic National Park entrance station	Yes
6	9.833	Olympic National Park entrance station[2]	
7	9.194	Near USGS gaging station (0.47 mile upstream)	
8	8.724	USGS gauging station near McDonald Bridge	
9	8.559	Downstream end of dike along right side of river	
10	8.435	Monitor side channels only in right floodplain	
11	8.112	Just upstream from the mouth of Little River	Yes
12	7.846	Upstream side of Highway 101 Bridge	
13	3.787	Existing Dry Creek Water Association well & power line crossing	Yes
14	3.482	Near water diversion tunnel intake upstream of proposed diversion structure	
15	3.209	Just downstream of single-lane bridge (possible gaging station location)	
16	3.011	Across from State Fish Rearing Channel	Yes
17	2.693	Near upstream end of industrial water supply pipeline	
18	2.191	Upstream of entrance to Hunt Creek Side Channel	
19	1.595	High terrace upstream from Corps of Engineers Levee	
20	0.937	Lower Elwha flood plain	Yes
21	0.584	Eroding glacial bluff	
22	0.221	Near river mouth	

[1] Based on 2001 aerial photography as measured from the mouth of the Elwha River.
[2] Repeat cross-section surveys at this location may not be possible because of high velocity and shallow flow, but river stage and bank erosion should be monitored.

The initial channel geometry and bed-material size gradation will be documented at each cross section. Survey monuments, bank erosion pins, and staff gages will also be installed and surveyed at each cross section prior to dam removal. In addition, continuous stage recorders will be installed at selected locations (see Table 10). Stage recorders will indicate aggradation if increases in river stage occur without a sufficient increase in discharge. A network of monuments was established in 1994 for cross sections between the Glines Canyon Power plant and the Elwha River Road Bridge. However, the continuing presence of these monuments needs to be verified and they will be replaced and resurveyed where necessary. New monuments will need to be installed and surveyed at cross sections downstream from the single-lane bridge. River cross sections can presently be defined from the 2001 LIDAR and channel survey (see section 2.10). However, new cross section surveys may be necessary at some locations if there is significant channel change prior to dam removal. The bed-material size gradations were measured in 1994 by Gilbert and Link (Reclamation, 1996). These size gradations may not have significantly changed at most locations because the riverbed is generally thought to be armored due to the majority of sediment supply being cut off by the upstream dams. However, the initial bed-material size gradations will be re-observed at monitoring cross section locations just prior to dam removal. Documentation should include a photograph of the bed-material at the site and comparison to previous observations from Gilbert and Link for the reach being observed. Observations would need to be accomplished during low flow periods when the water is clear. Monitoring of bed-material at cross-sections located in a deep pool may not be possible with the current visual technique.

Once the dam has been removed to below the level at which sediment has accumulated against it, the first wave of coarse sediment will be eroded from the reservoir and transported into to the downstream river channel. This event will initiate the monitoring of the downstream river channel for potential riverbed aggradation and increases in flood stage. The length of time for the river to transport sand and gravel from Lake Mills to the river mouth is expected to range from weeks to months. Therefore, the monitoring will begin at the upstream reaches first and then expand to the downstream reaches. If the bedload wave cannot be tracked for any reason, monitoring of cross-section river stage would begin at all sections during the next spring or fall low-flow period.

The speed of first the bedload wave can be tracked by monitoring the particle sizes on the riverbed. The present bed of the Elwha River is armored with boulders and bedrock from Glines Canyon Dam downstream to about river mile 2.5 (Gilbert and Link, Reclamation, 1996). Between river miles 13.5 (below Glines Canyon Dam) and 2.5, the particle size on the riverbed, that is greater than 90 percent of all other particles (D_{90}), is 300 to 600 mm (boulder size particles). Between river miles 2.5 and 1.0, the D_{90} particle size is 125 to 300 mm (cobble size). However, over 95 percent of coarse sediment volume in the Lake Mills delta is sand and gravel with a particle size less than 19 mm. Therefore, sediment particles from the reservoirs will be significantly smaller than the existing riverbed material.

Once sand and gravel has first been transported past either dam, riverbed material will be monitored by either visual observation through the water or by sampling if the water is too turbid to see the bottom. This would be done on a daily basis at the first four cross sections downstream from the dam where sediment had been released (see Table 5). The bed-material

Comment [BoR13]: Is this realistic?

samples could be preserved for laboratory analysis under the restoration monitoring program. Monitoring of each cross section will continue until the presence of sand and fine gravel is observed at the section, indicating the bedload sediment wave had reached the cross section. Once the sediment wave reaches one or all of the upstream four cross sections, the bed-material monitoring will shift downstream. If only the upstream cross section showed a change in sediment size, the monitoring will only shift downstream one section. If all four cross sections showed a change, the monitoring will shift downstream to the next four cross sections to determine if the sediment wave had reached those sections, and so on. Monitoring will always continue to be shifted downstream so that the cross section bed-material monitoring will be four cross sections ahead of the bedload wave. It is not known how fast the sediment wave will move, but monitoring will continue until the first bedload wave from Lake Mills reaches the mouth of the Elwha River. It will be valuable to monitor additional sediment waves resulting from subsequent releases of sediment to assess the progression of deposition on the river bed and the variation in rates and volumes of sediment transport. However, this additional monitoring would have to occur as part of the restoration monitoring program.

Comment [BoR14]: What if it takes longer than 3 years after dam removal?

Monitoring of river stage will be initiated at each monitoring cross section once the bedload wave reaches that particular reach and will continue throughout dam removal and for 3 years following dam removal (see Table 4). Therefore, if a subsequent sediment wave causes significant aggradation at a particular cross section, it would be detected through this monitoring activity.

Bed-material samples will be collected using an USBM-54 sampler, either from a bridge, by wading (where safe), or by boat with a hand-held sampler. Because the existing riverbed is armored, the bed material sampler is not expected to collect any material until the reservoir sediment has reached the cross section. If the riverbed is visible through the water, then the presence of reservoir sediment will be detected visually. For the adaptive management program, the median grain size of the sediment samples will be photographed with a scale and the median particle size will be visually estimated and recorded (e.g. fine sand, medium sand, coarse sand, fine gravel, medium gravel, coarse gravel, small cobble).

Comment [BoR15]: Not likely on our budget or for bridges available

Riverbed aggradation has been predicted that will increase the existing 100-year flood stage by a maximum of 2.5 ft (for a discussion of predicted increases to riverbed aggradation and water surface elevations see Randle, 2002). The flood mitigation plan calls for raising the height of existing levees and the construction of some new levees to control flooding. Stage-discharge rating curves for existing cross sections will initially be predicted from the calibrated hydraulic model, up to the 100-year flood. These predictions will then be verified from field measurements prior to dam removal.

During dam removal, the river stage will be monitored on a weekly basis to determine if there is an increasing trend in water surface elevation for a given river flow. The river stage will be measured from a local staff gage or surveyed from a local monument as a backup. At six critical cross section locations, continuous stage recorders will be installed (see Table 5). These continuous stage recorders will include telemetry to a WEB site. If river stage increases by more than 1.0 foot from the initial conditions for a given river discharge, then a cross section survey will be performed as soon as safe flow conditions permit. The survey will be performed across

Comment [BoR16]: Should we just say we see a general shift in rating curve or do we have a target Q all portions of the channel and flood plain that may have changed. The hydraulic model will then be updated to predict the water surface elevation corresponding to the 100-year flood.

As part of this project, flood protection mitigation measures have been designed and will be implemented prior to the start of dam removal to accommodate a 2.5 ft increase in the 100-year flood stage. Therefore, it is not acceptable to allow riverbed aggradation to cause the 100-year flood stage to increase by more than 2.5 ft beyond initial conditions. Although some riverbed aggradation is expected, an adaptive management response would be initiated if the riverbed aggradation causes the 100-year flood stage to increase by more than 2 ft beyond initial conditions. Using 2 ft as the threshold to initiate action should allow adequate time before the design limits of the flood mitigation are exceeded. If the riverbed aggradation is at a localized area (detected at one cross section), sediment could be mechanically removed from the river channel if infrastructure or property is at risk, or flood protection structures could be built or improved upon if already in place and not adequate. If large woody debris is present at the site of localized aggradation, discussions would be held with biologists and resource managers to determine if any action is necessary, what potential consequences might be to habitat versus infrastructure and land. If the riverbed aggradation is system wide (detected at several continuous cross sections within one reach) and threatens infrastructure and property, dam removal would have to be temporarily halted until river flows rework the aggraded sediment.

Deleted:

5.4.2 Restoration Monitoring

Both the short-term release of stored reservoir sediments and the long-term re-establishment of pre-dam bedload sediment transport regimes are expected to significantly influence the particle size composition of channel substrate. Specifically, it is hypothesized that there will be a significant increase in sand and gravel-sized sediments on the riverbed, resulting in a decrease in average bed material particle size and an increase in annual bedload transport. In addition, it is expected that there will be a broader range in the local distribution of particle sizes and an increase in the spatial variability of substrate size distributions.

Substrate size characteristics are important attributes of aquatic habitat, and the recruitment of sand and gravel following dam removal is expected to provide important components of habitat presently absent in the river downstream from the dams. However, elimination of the two reservoirs also means that there will be increases in suspended sediment transport. During the first few years following dam removal, fine sediment intrusion into coarser gravel and cobble substrates may be an issue influencing aquatic habitat quality. Bed sediment grain size distributions, especially in relation to critical habitat features, is a potential subject of restoration monitoring.

Restoration monitoring of the bedload sediment erosion wave could answer many questions of interest to the Elwha River Restoration Project and to other potential dam removal projects such as:

- What are the sediment transport rates of sand and gravel from the reservoirs?
- As the bedload wave progresses downstream, are sediment particles sorted by size so that the finer particles move down ahead of coarser particles?
- Do sediment transport rates for sand and gravel increase as more of the existing cobbles and boulders of the existing river channel are covered with finer particles?
- What volume of sediment has aggraded within the channel bed and how does this volume change over time?
- Where, when, and over what timeframes do bed habitat features such as pools, riffles, bars, and backwaters form? What are the hydraulic characteristics associated with the formation of these features? How dynamic are these features during the dam removal process and over the longer term recovery period?

To answer these questions, additional data analysis beyond the adaptive management monitoring tasks would need to be accomplished. A sediment budget could be formulated to track sand and gravel size sediment movement from the reservoirs through the system to the mouth of the Elwha River (see Section 5.9). The repeat cross-section surveys from the adaptive management monitoring will help to document the amount and level of riverbed aggradation at unique locations along the project reach. However, additional cross-section surveys at much closer distance and time intervals will be needed at selected reaches to determine the volumetric rates of channel aggradation and rate of bedload waves moving through the system to incorporate into the sediment budget. Reaches could be identified downstream of each dam based on geologic features, such as constricted canyon areas, or based on channel width, such as 7 to 10 channel widths in length. For each selected reach, either a comprehensive survey using Lidar and/or boat with GPS could be used, or about 40 cross sections would be needed at distance intervals of less than one-quarter of the channel width. The channel portion of the surveys would need to be repeated at least four times a year to measure the dynamic channel response. The short distance interval would enable topographic comparisons over time for the selected reach. These topographic comparisons would also document the formation and erosion of river bars and the channel response to the deposition of large woody debris.

5.5 Aquifer Characteristics

If significant quantities of fine river sediment (silt and clay) were to enter the alluvium surrounding the river channel, then the infiltration rate from the river to the alluvial aquifer would decrease until these fine particles were eroded during floods and lateral channel migration. A decrease in the infiltration rate from the river to the aquifer could also reduce the yields from the Tribal infiltration gallery and the City Ranney collector because they are directly connected to the river. If the infiltration rate from the river to the alluvial aquifer were to decrease, then recharge to the aquifer would decrease. This would decrease the discharge from the aquifer to the Strait of Juan de Fuca and that could allow sea water to intrude into the freshwater alluvial aquifer near the river mouth. Over the short term (within three years following dam removal), this could possibly affect the water quality of the Tribal wells near their fish hatchery because they are somewhat close to the river mouth.

Comment [BoR17]: What are these wells used for? Hatchery?

The risk of fine sediment particles being entrained from the Elwha River into the groundwater flow would be greatest during periods of low river flow, high sediment concentration, and during the maximum rate of groundwater withdrawal. Although the risk that high suspended sediment concentrations in the river would enter and reduce the infiltration rate from the river to the alluvial aquifer is believed to be small, there is no reliable way to quantify the risk. However, the risk could be lowered by reducing the rate of groundwater withdrawal during periods of high sediment concentration and low river flow. For example, when the river flow is less than 1,000 ft^3/s, suspended sediment concentrations are expected to exceed 1,000 ppm between 140 to 170 days during dam removal. Suspended sediment concentrations are expected to exceed 5,000 ppm between 27 to 42 days when the river flows are less than 1,000 ft^3/s.

In the vicinities of the Tribal infiltration gallery (river mile 1) and the City Ranney collector (river mile 3), the river channel has migrated in recent years to the west and away from these water intake facilities. Decreases in water yields have been reported in both of these cases. Any additional channel migration, farther to the west, would likely result in additional reductions in water yields. During dam removal, sediment deposition along the lower Elwha River is expected to cause the channel to follow a straighter alignment and steeper slope. Continued sediment deposition along the channel is expected to result in a braided plan form with continued channel migration across the floodplain. Water yields from the infiltration gallery and Ranney collector would tend to increase as the channel migrated toward the east. Since there is more room for the channel to migrate east, channel migration during dam removal is expected to generally increase the water yields from the infiltration gallery and Ranney collector. Over the long term, the river is expected to become more meandering once the processes are driven by natural sediment loads and yields for the infiltration gallery and Ranney collector would tend to fluctuate with the lateral position of the channel.

An increase in river water surface elevations would be expected to cause an increase in groundwater levels and a subsequent increase in well yields. Groundwater elevations would only significantly increase if there were a significant increase in the river water surface elevations, resulting from aggradation of the riffles. If there were an increase in river water surface elevation, then the groundwater elevations next to the river channel would increase by the same amount, but this increase would diminish with distance away from the river. The maximum possible increase in groundwater elevations, as a result of dam removal, is estimated at 2.5 feet, but the actual increase may be closer to zero (Randle, 2003). An increase in groundwater levels could pose a problem for septic systems on the Tribal land and possibly for dewatering of the hatchery ponds.

5.5.1 Adaptive Management Monitoring

The adaptive management monitoring of the aquifer characteristics will include measurements of groundwater elevation and yields from production wells. Groundwater elevations would be continuously monitored from the observations wells listed in Table 12. This monitoring would begin three months prior to dam removal and continue during dam removal and for three years after dam removal. The initial monitoring would establish the baseline conditions prior to dam removal. Any trends in groundwater elevations would be tracked along with any trends in riverbed aggradation to determine if there is a correlation. If groundwater elevations began increasing to level of concern, as a result of riverbed aggradation, then corrective actions would be taken. These actions could include pumping of the local aquifer, removing sediment deposits from the river channel, or slowing the rate of dam removal until the groundwater elevations return to normal levels. Sediments removed from the river channel would need to be disposed of according to agreed upon regulations and permitting documents applied for each project.

Table 12. Observation well monitoring sites

Well Location Number	Sites Descriptions
O1	Elwha Reservation well near hatchery infiltration gallery
O2	Washington State well near the Fish Rearing Channel wells
O3	City of Port Angeles well near Ranney collector
O4	Dry Creek Water Association well near their municipal wells
O5	URS well on the Elwha Reservation

Comment [BoR18]: What is purpose of this well?

Well yield measurements will be conducted prior to dam removal at the sites listed in Table 13. The Elwha Reservation community wells are set back far enough from river that yield tests are not required and, therefore, are not included in Table 13. If there are concerns that well yields have decreased because of dam removal, the yield measurements could be repeated during dam removal at the sites listed in Table 13 to determine short-term effects. In addition, the well yield measurements could be repeated about three to five years after dam removal when sediments impacts from the reservoirs are no longer detectable to determine any long-term effects.

Table 13. Well yield measurement sites		
Well Location Number	**Number of Wells**	**Sites Descriptions**
Y1	1	Elwha Reservation Hatchery infiltration gallery
Y2	3	Washington State wells for the Fish Rearing Channel (new wells may be installed to increase capacity from 2 to 8 ft^3/s)
Y3	1	City of Port Angeles Ranney Collector (the cost of the yield measurement is assumed to be included in Water Treatment Plant Costs)
Y4	2	Dry Creek Water Association wells (the yield test would not be needed if they establish new wells)

Well yields may be limited by pump capacity and not necessarily show changes in permeability within the aquifer. Another option would be to pump water from the production wells and drawdown the aquifer, but this may be costly and time consuming. The pumped water could be discharged back into the river or sea. If well yields decrease significantly due to the plugging of the aquifer with fine sediment, mitigation measures will need to be taken to ensure delivery of water. For example, the riverbed surface in the vicinity of the well could be scraped to attempt to release the fine sediment from the bed material. This type of activity would require permits to work in the wetted channel. The summary of adaptive management actions is listed in Table 14.

Table 14. Summary of Adaptive Management Monitoring Activities Aquifer Characteristics			
Measurement parameter	**Well Location Numbers**	**Frequency**	**Duration**
Install equipment to monitor water levels in wells	1, 2 ,3 and 4	once	At least 3 months prior to removal;
Monitor well water level	1, 2 , 3, 4, and 5	continuous	3 months prior to removal; 3 years during dam removal and 3 years after dam removal
Monitor well yield: initial conditions	1, 2, and 4	once	Prior to dam removal
Monitor well yield: final conditions	1, 2, and 4	once	3 to 5 yrs following dam removal when reservoir sediment impacts are no longer detectable
Monitor well yield: contingency measurement during dam removal	1, 2, and 4	once	During dam removal if needed

5.5.2 Restoration Monitoring

Restoration monitoring related to the aquifer characteristics could focus on data collection during dam removal to determine the feasibility of using wells and infiltration galleries to provide municipal and industrial water supplies during other dam removal projects rather than surface water diversions. This was initially proposed for the Elwha River Restoration Project, but project managers decided to continue the surface water diversion due to the potential risks that the aquifer could become plugged with fine sediment as a result of dam removal. Aquifer data collected during this project could be used to assess the actual risk of fine sediment plugging the aquifer.

5.6 River Channel Planform and Channel Geometry

Increases in bedload sediment transport, channel aggradation including mid-channel bar formation, and large woody debris accumulations are all mechanisms that contribute to increased rates of lateral channel adjustment and changes in channel geometry. Lateral planform adjustments can occur through bank erosion and channel migration, channel avulsion, or channel bifurcation. Planform adjustments may include changes in basic river classification (e.g., from meandering to anastomosing or braided), modifications in sinuosity, changes in hydraulic geometry, and changes in channel bar forms. Lateral planform adjustments are expected to be more pronounced in low-gradient reaches where alluvial materials form the channel bed and valley bottom than high-gradient or bedrock canyon reaches.

Lateral channel adjustments and modifications in planform are expected to be part of the long-term restoration of the fluvial ecosystem. However, some local lateral adjustments may not be desirable because they threaten existing infrastructure, private property or cultural or historic sites, or reduce the water supply to private wells. In these cases it may be necessary to implement mitigative measures such as providing bank protection to limit further erosion, relocating or retiring infrastructure or wells, or using log jams or other flow deflection techniques. Local planform response (including rates of response) especially in locations where infrastructure is potentially threatened, are potential subjects of adaptive management monitoring. Larger, reach-scale and system-scale evolution of channel planform including bank erosion and changes in channel pattern and bar forms (including the association of changes with their causative factors) are potential subjects of both adaptive management and restoration monitoring.

In addition to channel planform, the hydraulic geometry (width, depth, cross-section shape, local gradient and hydraulic roughness) can also change. Hydraulic geometry changes influence flow velocities and all these changes can potentially influence the quality and diversity of aquatic habitat. The evolution of hydraulic geometry at both the local and reach scales, both in the former reservoir beds and in downstream channels, are potential subjects of restoration monitoring. To the extent that cross-section hydraulic geometry at critical locations is useful in improving predictive modeling of short-term channel response to dam removal, it may also be a potential subject of adaptive management monitoring.

5.6.1 Adaptive Management Monitoring

The following locations along the river have been identified as critical infrastructure that can not tolerate bank erosion as a result of dam removal. These sites will be visually inspected and photographed once per week during and for 3 years following dam removal by the on-site geomorphologist to determine if bank erosion is occurring that could potentially cause river flow to threaten infrastructure:

- Altaire Bridge (RM 12.612)
- Flow split between Altaire Campground and Ranger Station
- Park road and entrance station (RM 9.833)
- Upstream side of Hwy 101 Bridge (RM 7.846)
- River channel leading to the diversion dam
- U.S. Army Corps of Engineers levees
- Private levees

Bank erosion pins will be placed at each of the cross sections listed in Table 5 and will also be monitored for signs of erosion. Additional areas of the river are currently susceptible to bank erosion, and will likely continue to be subject to erosion as the river naturally migrates across the floodplain in the future. An inventory of presently eroding banks along the active river channel will be accomplished prior to dam removal to provide baseline data of existing erosion areas. This survey would occur either from roads or during the longitudinal profile survey during the first year of dam removal prior to the release of any coarse sediment from Lake Mills. Overflow channels in the floodplain would not be included in the inventory.

Unanticipated bank erosion will be stopped by installing or enhancing bank protection structures. These visual inspections will be conducted by the same people that are measuring river stage (see section 5.4.1) and visually inspecting large woody debris (see section 5.7.1). Since the visual inspections for bank erosion can also be conducted at the same time, no additional monitoring costs are anticipated. Costs to design and install bank protection mitigation are dependent on individual site conditions and thus are beyond the scope of this monitoring plan and cost estimate.

Comment [BoR19]: Not likely now that I reread this, maybe once per month or once per drawdown increment after reservoir pool is gone.

Comment [BoR20]: Project staff?

Comment [BoR21]: How often?

Comment [BoR22]: Should we limit this to say banks along private property, infrastructure, or roads?

Comment [BoR23]: If not along road is it feasible to monitor all the time by geomorphologist or even worry about?

Comment [BoR24]: Shouldn't we say will be evaluated by project mgmt team to determine if any action is needed?

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5.6.2 Restoration Monitoring

The restoration of a supply of sand and gravel to the downstream river channel will cause channel planform to exhibit a complex response. The existing channel is likely more narrow and meandering than under natural conditions. The expected response from dam removal is at least some riverbed aggradation, channel widening, and a straighter, more braided channel. The aggradation is also expected to cause increased rates of channel migration. Many of these channel alignment changes will erode portions of the flood plain and riparian forest, introducing large amounts of wood debris into the river channel. This additional woody debris will also cause additional complex channel response. The documentation and understanding of these and other complex channel responses is the task of the Restoration Monitoring Program (see Section 5.4).

The primary monitoring methods will be to obtain a series of repeat aerial photographs and perform a river channel survey of the longitudinal profile and horizontal alignment of the river. Measurements of interest will include the rate of planform change after dam removal compared to pre-dam removal rates downstream of the dams and to the Krause Bottom and Geyser Basin reaches upstream of the dams. The repeat cross-section surveys (see section 5.4.1) will be used to help analyze the local rate of channel migration and bank erosion and the corresponding amount of channel aggradation.

5.7 Large Woody Debris Recruitment, Transport and Distribution

Large woody debris form important habitat features in Olympic Peninsula streams, and it interacts with flow and sediment transport to influence river channel morphology. In addition, log jams can potentially threaten human infrastructure such as bridges and water intake facilities. It is hypothesized that the recruitment and amount of large woody debris in the Elwha River has been substantially reduced downstream from the dams. This is because the reservoirs serve to accumulate and store woody debris in transport and because reductions in lateral processes, downstream from the dams, results in decreased bank erosion and local wood accumulations. It is anticipated that a response to dam removal will be a substantial short-term increase in the amount of large woody debris accumulation and transport in the river downstream from the dams and on the former reservoir beds. Over the long term, large woody debris regimes should approach a natural equilibrium reflecting current watershed conditions upstream of the reservoirs.

Most large woody debris accumulations will be natural phenomena and will contribute to the long-term restoration of the Elwha River ecosystem. However, certain log jam accumulations may threaten infrastructure or instigate channel adjustments that, in turn, threaten infrastructure or private property. In this latter case, certain mitigation measures may be required (log-jam removal). Log jams that potentially threaten infrastructure are potential subjects of adaptive management monitoring. The recruitment, accumulation, distribution, and transport of large woody debris and their relation to fluvial processes are potential subjects of restoration monitoring.

Comment [BoR25]: Does same 2 ft of increase to local stage apply if log jams forms?

5.7.1 Adaptive Management Monitoring

The following locations along the river will be visually inspected and photographed once per week to determine if any log jams have formed that could cause river flow to threaten infrastructure:

- Altaire Bridge
- Flow split between Altaire Campground and Ranger Station
- Park road and entrance station
- Hwy 101 Bridge
- River channel leading to the diversion dam
- U.S. Army Corps of Engineers levees

- Private levees

In general, potential threats will be from riverbank erosion. A log jam could also cause a river channel avulsion that may direct flow into a structure or away from the diversion dam. If such a log jam were to occur, the woody debris will be removed with heavy equipment or possibly by blasting. There is a possibility that extensive woody debris jam (especially in the bedrock canyons) could block the passage of migrating fish. If necessary, such a log jam will be removed.

These visual inspections will be conducted by the same people that are measuring river stage (see section 5.4.1). Since these visual inspections can also be conducted at the same time, no additional monitoring costs are anticipated.

5.7.2 Restoration Monitoring

There are several important questions that could be answered from restoration monitoring of large woody debris. These questions relate to the recruitment, accumulation, distribution, and transport of large woody debris and their effect on river channel processes such as aggradation, river width, depth, velocity, planform, and the rate of channel migration across the flood plain. Studies could focus on the entire river system and assess wood budgets, or could be focused in on a particular area prone to deposition of woody debris. Specific questions and funding have not been generated for this restoration monitoring effort, but there are a variety of research topics that could be explored in this area not only for sediment monitoring purposes, but also for biological monitoring of habitat. For example, the effects of large woody debris on channel width, channel complexity, the rate of channel migration, and fish habitat would be of great interest.

5.8 Coastal Processes

The increases in sediment load to the Strait of Juan de Fuca will likely be quite high during the dam removal period. Over the long term, the natural sediment supply from the upstream watershed will again reach the lower river. The increased sediment supply will reverse any historic channel degradation trends and increase suspended sediment concentrations and turbidity over existing conditions. The short- and long-term increases in sediment delivery to the Strait are expected to influence several processes and conditions including the location and extent of the near-shore turbidity plume, the geometry of the river delta and the location of the beach line, the rate of long-shore sediment transport (especially in the sand- and gravel-size ranges), and potentially, the geometry of Ediz Hook. Some increased sediment deposition on near-shore marine environments is also expected to occur.

5.8.1 Adaptive Management Monitoring

No coastal monitoring activities have been identified for the Adaptive Management Monitoring Program because there have not been any resource management objectives identified that would alter the dam removal operations. Fish windows have been identified to help provide time periods of lowered suspended sediment concentrations so fish will not be deterred from migrating into the Elwha River. Monitoring results from the biological monitoring program may indicate that the timing and duration of fish windows may need to be shifted or could be reduced.

5.8.2 Restoration Monitoring

However, several monitoring activities have been suggested that would build upon existing monitoring methods and data and provide valuable information to better understanding the impacts of dam removal on coastal processes. For example, the location and extent of the near-shore turbidity plume, the location of the river-delta beach line, and the change in gradation of sediments deposited on the beach, and the effects of increased long-shore drift on the geometry of Ediz Hook are some potential subjects of long-term restoration monitoring. The substrate quality of near-shore marine habitats may also be a potential subject of long-term restoration monitoring.

The physical monitoring of coastal processes during and after dam removal will build upon existing monitoring techniques and include monitoring the location and extent of any turbidity plumes, beach bathymetry and shoreline position, and deposition along Ediz Hook. All three of these parameters depend directly on the rate and quantity of sediment being transported to the mouth from the upstream reservoirs and watershed. It is recommended that monitoring begin with present conditions to extend the baseline data set, and continue for at least five years after dam removal.

5.8.2.1 Turbidity Plume

High flows and sediment releases during dam removal can be expected to cause fresh-water turbidity plumes that extend out into the Strait. The size of a plume can be expected to depend upon the amount of river flow and the sediment concentration (silt and clay) at any given time. The position of the plume can be expected to depend on tidal direction (ebb/flood) at the time. However, observed plumes have been tracked to go eastward (not influenced by tide). The rate of dispersion of a plume can be expected to depend on the wave conditions at the time. Plume visibility (turbidity) can be expected to depend on the relative amount of silt-clay in suspension at the time. The silt and clay in a plume should quickly flocculate as plume salinity increases through mixing of fresh and salt water at the edges of a plume, and then settle to the bed of the Strait. This river silt and clay is not significant to beach formation and beach mechanics.

Measurement of the suspended sediment concentration in the river near the mouth and the turbidity plume in the Strait will quantify the amount of fine-sized suspended sediments entering the coastal area. The location and extent of the turbidity plume may affect migrating fish as they attempt to enter the river mouth. Sediment in the turbidity plume may also affect marine life.

A monitoring location would be established just below the last riffle upstream of the river mouth to determine the degree of mixing of suspended sediments. The section will be located at the bottom of the riffle rather than in a pool to ensure the suspended sediments are well mixed. Both turbidity and concentration will be sampled to establish a relationship between the two parameters. Concentration will be sampled once per week while turbidity will be measured on a continual basis.

The turbidity plume in the Strait will have to be monitored from a network of buoys to determine the location, extent, and duration. The turbidity plume likely will change positions over time as the currents in the Strait change and as the river-channel changes position at the mouth. Aerial photographs could also be used to monitor the turbidity plume, but it may be difficult to acquire aerial photographs on a frequent enough basis to document changes in the position and extent of the turbidity plume. Satellite photography may also be utilized to monitor the turbidity plume.

5.8.2.2 Beach Bathymetry and Shoreline Position

The coarse fraction of the river sediment load (sand, gravel, and cobbles) in a plume will act as bedload and will be transported along the coast in shallow water. Only this coarse portion of the sediment load in a plume will be added to the littoral transport material that nourishes the beach.

Presently, the Elwha River enters the Strait of Juan de Fuca with no evidence of an estuary zone; instead the channel width is essentially the same as for the river channel upstream. The upstream influence of the ocean tide is estimated at 1,200 ft upstream of the shoreline (Schwartz, 1994). Maury Schwartz and Jim Johannessen have already accomplished semi-annual physical monitoring at the Elwha Delta from 1996 to 2001. In addition, photogrammetry and historical maps are being used to assess shoreline change for the time period between the early 1900's to present (Johannessen, written communication, 2001).

From 1996 to 1999, beach erosion was measured to range from 0 to 67 ft (Schwartz and Johannessen). The present and past delta retreat to the south is only partly related to the presence of the dams, but also due to a much longer geological history of retreat. Dam removal will not fully reverse the long-term trend of delta erosion. Dam removal may locally halt or offset the retreat for some years while river sediment input to the coast is quite large. Erosion at the west bluff near the river mouth has added material to the shoreline and helped retard the rate of beach retreat. Erosion control along the base of the bluff, if it were implemented to halt bluff erosion, will cut off this input of sediment to the beach.

The lateral position of the river mouth at the coast is presently limited by a nearby non-federal levee to the west and a more-distant federal levee to the east. However, the mouth is able to shift laterally between these widely spaced levees. Currently, the channel position is quite close to the non-federal levee to the west but historical mapping shows that the channel has been in several locations at the mouth and at times to have had multiple channel paths. Monitoring of the beach bathymetry and shoreline position will help to answer the following questions:

- How does the beach-line change before, during, and after dam removal?
- How is marine life affected by the shifting beach line?
- How does the riverbed elevation and channel position change at and near the mouth?
- Does the increased sediment supply, during and after dam removal, change the littoral transport past Angeles Point and at the lake east of the point?
- What height, width, and length of the delta beach berm are required to protect land from flooding during storm surges?

<u>Beach Profile Surveys</u>

Monitoring of the beach bathymetry and shoreline position could be accomplished through aerial photography and ground surveys at the edge of the water and at lower-low tide[3]. Ground survey techniques including semi-annual beach profiling at locations and times established by Schwartz and Johannessen are already in place. Profiles could be surveyed once during a late March to early April timeframe, and once during early September to match previous data sets. An additional set of beach profiles could be surveyed following large winter storms to document sudden changes. Locations of profiles are suggested at seven existing baseline profile locations with the addition of three new profiles. Table 15 lists the proposed profile locations.

[3] There are two low tides in each tidal cycle (so usually two low tides in each day). These two low tides are not quite the same height because one tide is generated by the gravitational interaction with the sun (which is small), and the other is generated by the gravitational interaction with the moon (which is not so small). Since the two low tides (or water levels) are different levels of low, one is naturally the higher low water (higher low tide) and the other is the lower low water (lower low tide). Mean Lower Low Water is the average of the lower low water height of each tidal day (ie average of the lowest low tide from each day).

Table 15. Suggested profile locations for coastal monitoring.		
Profile	Data History	Location
1 to 7	1996-2001	Not known
8	New	West of the non-federal levee in Freshwater Bay
9	New	At the beach east of and away from the immediate influence of Dry Creek
10	New (Some historic data in area)	At the eastern end of the delta (approximately 0.5-1.0 miles east of Dry Creek)

<u>Beach Berm Survey</u>
A survey profile along the top of the active storm berm twice a year (during spring and fall) will help document the degree of natural flood protection. Presently, there are seven existing monuments currently being utilized for the beach profile surveys that could also be utilized for surveying the storm berm. The survey along the top of the berm could be accomplished on the same days each spring and fall as the survey of the beach line. An additional berm survey could also be performed on the same day as the beach profile survey following any large winter storm in order to document any sudden changes.

<u>Beach Sediment Size Measurements</u>
It would be useful to compare the changes in grain-size distributions along the beach as a result of dam removal. Limited analysis of the sediment sizes along the beach has been accomplished in the past, but photographs from 1996 to 2001 documenting sediment sizes are available. In order to create a historical baseline set, the beach sediment visible in the photographs could be analyzed using new techniques that determine sediment gradation from a scaled photograph. Future monitoring of sediment sizes should incorporate grain-size analysis using either the photogrammetric technique or by doing physical sediment sampling in the field. New, permanent sample sites of the beach surface materials would need to be established for this monitoring effort between the edge of water (at lower-low tide) and the top of the existing berm.

<u>River Mouth Cross Section Surveys</u>
This work will be coordinated with river channel survey work in the upstream river channel. It is recommended that two transects be established with permanent benchmarks at the river mouth. Each cross section should have an aligned pair of permanent markers to allow the section alignment to be repeated each time it is measured.

5.8.2.3 Ediz Hook

Ediz Hook has historically been eroded as a result of the construction of Elwha Dam and Glines Canyon Dam along with erosion protection measures installed along the coastline to protect the industrial water supply. Ediz Hook is presently armored with large diameter rock riprap. A potential restoration monitoring task will be to evaluate whether there is a measurable increase in beach surface area along Ediz Hook as a result of the increased sediment supply during and after dam removal.

5.9 Sediment Budgets

Short-term and long-term sediment budgets for the Elwha River system from Lake Mills to the Strait of Juan de Fuca will be affected by dam removal and ecosystem restoration. At Lake Mills, the initial response to dam removal will be a major reduction in sediment storage over the short term. Sediment inputs from the upstream watershed will remain unchanged. For the river reach downstream from Glines Canyon Dam to Lake Aldwell, the initial response to dam removal will probably be for sediment inputs to exceed sediment outputs, and for sediment storage to increase. At Lake Aldwell, sediment inputs will initially increase but be exceeded by sediment outputs, resulting in a decrease in sediment storage over the short term. For the river between Elwha Dam and the Strait, the short-term response to dam removal will be for sediment inputs to exceed outputs, resulting in an increase in sediment storage.

Over the long term, a new dynamic equilibrium sediment budget is expected to be established for the entire reach of river between Lake Mills and the Strait. Once this new equilibrium is established, fluvial sediment storage for this reach is expected to undergo short-term periods of accumulation and release, but over the long-term to remain essentially stable. Thus, fluvial sediment inputs to and exports from the system will likely remain temporarily variable, but in long-term balance. The sediment balance for this system is of interest over the long-term restoration period, because it is not known how much sediment will be stored along the river and flood plains and how the longitudinal river profile will be adjusted. Also, rates of sediment input, export and transport influence planform processes and hydraulic geometry. Sediment budget variables including mass inputs, outputs and changes in storage, as well as local sediment transport rates are potential subjects of long-term restoration monitoring. Sediment storage changes in certain locations may also be of interest to adaptive management monitoring.

The adaptive management-monitoring program will provide some of the data necessary for computing the short and the initial long-term sediment budgets. However, additional data from restoration monitoring will be needed to complete the short and long-term sediment budgets. The following questions could be answered from the short and long-term sediment budgets:

- What fraction of reservoir sediments will be eroded and transported downstream during and after dam removal?
- How long does it take for the remaining reservoir sediments to become stable?
- How do suspended sediment concentrations increase during and following dam removal?
- How accurate are the predictions of reservoir sediment erosion, suspended sediment concentrations, and riverbed aggradation?
- Does the short-term riverbed aggradation associated with dam removal decrease or increase over the long term?
- Does riverbed aggradation primarily occur during low-flow periods when the dam is being removed and do high flows tend to flush the sediment?

- How much aggradation occurs on the flood plains over the short and long term?
- How does the river planform and channel geometry change in response to increased sediment loads during and after dam removal?
- How does aggradation affect flooding?
- Do aggraded river pools reform and are fine sediments flushed from the riverbed following dam removal?
- How does the bed material grain size distribution change over the short and long term?
- How much sediment deposition occurs at the delta over the short and long term?

Annual photogrammetry and/or LIDAR surveys, along with bathymetric surveys of the river channel and delta, would be excellent ways of determining the sediment budgets. The costs of LIDAR and photogrammetry can be high, but are much more efficient and cheaper than traditional survey methods when dealing with large areas as in this project. In addition, the costs for obtaining this type of data have been gradually declining over the last several years as technology improves. Sediment budgets could also be computed from continual sediment load measurements between gauging stations, but the errors in sediment load measurements could be significant.

Restoration monitoring should continue until at least the remaining reservoir sediments have become stabilized with new forest vegetation. Based on numerical modeling (Randle, 2002) this is predicted to take about three to five years. However, the long-term channel and flood-plain response to dam removal depends on the natural upstream sediment supply. A few decades may be required for the downstream river channel and flood plains to reach a dynamic equilibrium.

6.0 MONITORING PLAN SUMMARY

The objective of the Elwha River Restoration Sediment Monitoring Plan is to identify the critical monitoring parameters needed to evaluate the changes in physical river processes and characteristics both during and following the removal of the two dams on the Elwha River. The plan deals with the river's hydrologic, hydraulic and morphologic characteristics, sedimentation processes, interactions among flow and sediment transport, and aquifer responses.

For purposes of this plan, adaptive management monitoring is used to describe monitoring tasks that are necessary to accomplish dam removal in a safe, controlled manner. Restoration monitoring is used to describe additional tasks that may not be necessary to accomplish dam removal, but will help scientists understand the long-term ecosystem restoration processes. The general monitoring categories related to sediment management are listed in Table 16 along with their applicability to the adaptive management and restoration programs.

The proposed objective, frequency, duration, and locations of adaptive management monitoring activities were identified along with the adaptive management responses that could occur as a result of these activities. Adaptive management responses as a result of sedimentation processes will be triggered by feedback from real-time monitoring tasks and could include several options:

- Accept the impact and proceed with dam removal and reservoir drawdown.
- Modify monitoring methods, locations, or frequencies.
- Modify water treatment techniques.
- Take remedial actions to locally protect downstream infrastructure, wells, and property.
- Alter the schedule of dam removal and reservoir drawdown.
- Temporarily halt dam removal and reservoir drawdown.
- Initiate emergency evacuation.

The timing and frequency of adaptive management monitoring tasks vary depending on the stage of dam removal. Some tasks must be accomplished prior to the start of dam removal, some during the reservoir drawdown, and others will not be initiated until the reservoir pool is essentially gone. The frequency of monitoring depends on the progression of sediment transport both in the reservoirs and in the downstream river channel. Additionally, during periods of high flow or fish windows when dam removal is temporarily halted, the frequency of some monitoring activities may be slowed or even delayed until dam removal is resumed. However, certain activities would continue during high flow periods (when river changes and coarse sediment transport are likely to occur) to help ensure protection of downstream infrastructure, property, and residents. The duration of various monitoring activities ranges between only occurring once to continuing for three years following dam removal or when impacts from the erosion and release of reservoir sediments are no longer detectable.

The adaptive management monitoring tasks that will be performed prior to and after reservoir drawdown and dam removal are summarized in Sections 6.1 and 6.2. An overview of the restoration monitoring program is summarized in Section 6.3. Aerial photographs showing the study area and proposed monitoring cross sections are shown in Appendix A.

Table 16. Subjects of Adaptive Management Monitoring and Restoration Monitoring

Monitoring Category	Adaptive Management	Restoration
Reservoir Sediment Erosion and Redistribution ➢ Delta erosion and downstream progression ➢ Release of coarse sediments from the reservoirs ➢ Re-establishment of reservoir flood plain and vegetation	X	X
River and Reservoir Hillslope Stability	X	X
Water Quality (Suspended Sediment Concentration & Turbidity)	X	X
Riverbed Aggradation and Flood Stage ➢ Bed material size measurements ➢ River water surface elevations ➢ Channel geometry	X	X
Aquifer Characteristics ➢ Water table elevations ➢ Well water yields, quality	X	X
River Channel Planform and Channel Geometry	X	X
Large Woody Debris Processes	X	X
Coastal Processes		X
Sediment Budgets (Bedload Measurements, Channel Storage Changes, Comprehensive Channel Survey)		X

6.1 Adaptive Management Monitoring Tasks Prior to Dam Removal

The adaptive management monitoring tasks that will be required prior to dam removal are summarized in the list below:

- Bathymetric Survey of Lake Mills will be conducted to define initial conditions prior to reservoir drawdown.

- New stream gages will be installed to measure river stage, discharge, temperature, turbidity, and suspended sediment concentration at discrete locations along the Elwha River. A long-term stream gage already exists near McDonald Bridge (between the two reservoirs), but instruments will have to be installed to measure temperature, turbidity, and suspended sediment concentration. In addition, one new stream gage will be installed above Lake Mills at Goblins Gate (at the top of Rica Canyon) and another gage will be installed below Elwha Dam, between the Highway 112 Bridge and the single-lane bridge on Elwha River Road. A cable way will not be allowed at Goblins Gate, so discharge measurements will be made for this gage at the mouth of Rica Canyon (just upstream from Lake Mills) by boat or by cableway. Also, a cable way will not be allowed downstream of Elwha Dam so discharge measurements will have to be made by wading or by boat.

- Initial conditions will be measured at river cross sections where riverbed aggradation and flood stage are to be monitored (see Table 10). In addition, survey monuments, staff gages, and continuous stage recorders will also be installed. The following monitoring tasks will be conducted at these river cross sections prior to dam removal and reservoir drawdown:

  - Establish and survey monuments (bench marks) and bank erosion pins at river cross sections. A network of monuments was established in 1994 for cross sections between the Glines Canyon Power plant and the single-lane bridge on Elwha River Road. However, the presences of these monuments need to be verified and replaced and surveyed where necessary. New monuments will need to be installed and surveyed at cross sections downstream from the single-lane bridge. River cross sections can presently be defined from the 2001 LIDAR and channel survey (see section 2.10). However, new cross section surveys may be necessary at some locations if there is significant channel change prior to dam removal.

  - Establish and survey staff gages at all monitoring cross sections. In addition, install continuous stage recorders at the locations described in Table 10.

  - Compute and then measure the stage-discharge relationships at all monitoring cross sections. The HEC-RAS hydraulic model has already been applied to the Elwha River based on 2001 survey data (U.S. Army Corps of Engineers, 2002). This model will be used to compute the stage-discharge relationships at all monitoring cross sections for river flows up to the 100-year flood. River stage will be measured at these cross sections (for a range of flows during the winter flood season) and associated with the discharge measurements from the nearest stream gage to verify, and possibly adjust, the computed stage-discharge relationships.

  - Determine the initial bed-material size gradation at each river cross section prior to reservoir drawdown and dam removal. The bed-material size gradations were measured in 1994 by Gilbert and Link (Reclamation, 1996). These size gradations may not have significantly changed at most locations because the riverbed is generally thought to be armored and the reservoirs trap nearly all of the coarse sediment supply from the upper watershed.

  - Document (including photographs) any active bank erosion and the presence of log jams along the river channel, especially at the monitoring cross sections.

- Inspect all potential landslide areas prior to dam removal (reservoir areas documented in Burt, 2003). Existing landside areas include a large landslide on the upstream left side of Lake Mills and three small landslides along the downstream left side of Lake Mills (Burt, 2003), the river channel downstream from the Olympic National Park historic ranger district along the right bank, seven areas along Lake Aldwell of which four are very small in size (Burt, 2003), and a large area along the left side of the river near the mouth of the Elwha River.

- Install instruments to continuously measure water level in observation wells and measure the yield of all municipal wells

- Install WEB cameras overlooking Lake Mills, Glines Canyon Dam, Lake Aldwell, and Elwha Dam.

- Hire and train all adaptive management monitoring crews. Some of these crews may be hired as on-site project staff. Other crews may be comprised of technical staff within the Department of the Interior and the Lower Elwha Klallam Tribe. Contracts for technical support from universities and consultants will also be considered.

6.2 Adaptive Management Monitoring Tasks during Reservoir Drawdown and Dam Removal

The adaptive management monitoring tasks that will be performed during reservoir drawdown and dam removal are summarized in the list below:

- Monitor the reservoir sediment erosion and redistribution in Lake Mills and Lake Aldwell while the reservoir pool remains. Monitoring will consist of GPS measurements of the advancing delta front and the longitudinal slope of the main river-erosion channel in each reservoir. Visual estimates will also be made of the sediments remaining above the elevation of the river erosion channels. In addition, the reservoir WEB cameras will also be monitored during and after reservoir drawdown and dam removal.

- Inspect identified landslide areas along Lake Mills and Lake Aldwell, especially while a reservoir pool remains. Also, inspect the potential landside area along the Elwha River downstream from the Historic Ranger District and near the mouth.

- Once each reservoir reaches the critical elevation (485 ft for Lake Mills and 140 ft for Lake Aldwell), conduct a bathymetric survey of the remaining reservoir pool and river erosion channel and a topographic survey of the exposed reservoir sediment. From these surveys and the previous monitoring data, determine the portion of the reservoir sediment that has been eroded from each reservoir. Also, determine the portion of reservoir sediment that remains in a stable condition above the current reservoir elevation.

- After the reservoir deltas have reached the dams, monitor the width, longitudinal slope, and bank or terrace height of the main river-erosion channels once per dam removal increment. After dam removal, these measurements will continue once per quarter for an additional three years.

- Prior to reservoir drawdowns, continuously monitor the river flow, temperature, turbidity, and suspended sediment concentration. Continue these measurements until three years after dam removal. Suspended sediment concentration will either be monitored directly using light refraction methods or through turbidity. The LISST (Laser In-Situ Scattering and Transmissometry) instruments based on laser diffraction technology are a relatively new technique that may be implemented as part of this task.

- After each reservoir delta has reached the dam, monitor the downstream progression of the first bedload wave by sampling for sand- and gravel-size bed material at the cross sections listed in Table 10. After the first bedload wave has reached a monitoring cross section, periodically monitor the river stage and channel geometry. The channel geometry of these cross sections and a continuous longitudinal river profile will be resurveyed at least once per year. In addition to the manual staff gage readings, river stage will be continuously monitored at six key cross sections and reported on the WEB. Continue these measurements until three years after dam removal.

- The presence of large woody debris and bank erosion will be monitored during the dam removal process to provide early detection of problems for key infrastructure.

- During reservoir drawdown and dam removal, monitor well water levels along the river corridor. In addition, well yield would only be monitored at municipal wells where the yield is thought to be reduced as a result of dam removal.

6.3 Restoration Monitoring

Several monitoring subjects and questions were proposed in this document that fall in the category of long-term, or restoration monitoring. Answers to these types of questions will provide a valuable set of information and analysis that could be used to measure overall project performance. In addition, the information will result in a body of scientific knowledge applicable to both understanding and interpreting natural river restoration and healing, and will be applicable to the design of future river restoration projects in other locations.

Many restoration monitoring tasks could incorporate and build off of adaptive management monitoring data already being collected, but may increase the frequency and duration of monitoring. Other restoration monitoring tasks include activities not addressed in the adaptive management monitoring. These topics could in some cases begin prior to dam removal and continue after dam removal is completed until the remaining reservoir sediments have become stabilized with new forest vegetation. Stabilization of reservoir sediments is expected to continue for about three to five years following the completion of dam removal. However, the long-term channel and flood-plain response to dam removal depends on the natural upstream sediment supply. A few decades may be required for the downstream river channel and flood plains to reach a dynamic equilibrium and restoration monitoring in these categories could potentially be extended for a longer time period.

Restoration monitoring could be implemented by a variety of approaches that will emphasize partnerships between participating agencies, other interested parties, and academic institutions. Many of the proposed restoration monitoring tasks are an expansion of adaptive management monitoring tasks in order to provide more detail and frequency of data collection. For this reason, restoration monitoring tasks could be accomplished by the same individuals or agencies performing adaptive management monitoring providing some potential cost saving measures. It is recommended that proposals for restoration monitoring be brought to the attention of the Elwha Project Office so that information from technical analyses already accomplished can be provided. In addition, the project office would be able to refer the appropriate technical groups associated with the dam removal to ensure the proposed research builds off of and integrates with planned adaptive management monitoring activities.

6.4 Monitoring Plan Cost Estimates

Approximately 1.8 million dollars of project funding is currently available to support the adaptive management monitoring tasks. Budget estimates for adaptive management monitoring activities have been developed by the Bureau of Reclamation and the United States Geological Survey and are available as a separate document. The initial cost estimate for the adaptive management monitoring tasks is between 2 to 4 million dollars, depending on the frequency and number of stream gaging activities that will be funded. As new technology and or management questions arise, the cost estimates may need to be adjusted.

No project funding is currently available for restoration monitoring, but other research funding sources may be available to support these activities. The restoration monitoring program will provide valuable information on the rate that the river system approaches a dynamic equilibrium. In addition, restoration monitoring will provide information that will be particularly valuable to other restoration projects involving dam removal. A restoration monitoring program could easily cost as much as the adaptive management program. Although detailed cost estimates are not provided in this report, concepts for research ideas are presented that could be expanded into funding proposals by interested parties.

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Appendix A: Aerial Photographs of Project Study Area and Locations of Monitoring Cross Sections

Appendix B: Future Reservoir Sediment Stability

Tim Randle and Jennifer Bountry, June 14, 2005

Executive Summary

The removal of Elwha and Glines Canyon Dams on the Elwha River is expected to increase suspended sediment concentrations and turbidities in the downstream river channel. Suspended sediment concentrations and turbidities will be temporarily large during the erosion of reservoir sediment, but then decrease to natural levels that presently exist upstream from Lake Mills. Water treatment plants and new wells will be constructed to mitigate for the increase in suspended sediment concentration caused by the erosion of reservoir sediments.

Criteria are presented in this document to determine when the erosion of reservoir sediments has essentially stopped or slowed to negligible levels such that suspended sediment concentrations and turbidities have reached natural conditions in the Elwha River downstream from the former dams. The determination of when natural suspended sediment concentrations and turbidities are achieved, downstream from the dams, would be based on the results of monitoring data from river flow (upstream and downstream from the dams), monitoring data from the former reservoir areas, and from the results of a terrace bank stability assessment of the former reservoir areas.

A determination that natural conditions have been achieved for suspended sediment concentration and turbidity would be based on achieving the following three conditions:

Condition 1: Stable Relationship between Upstream and Downstream Suspended Sediment Concentrations or Turbidities

Condition 2: No Significant Change in Reservoir Sediment Volume

Condition 3: Hydrologic and Geomorphic Evidence of Stabilized Reservoir Sediments

Introduction

Prior to the construction of the Elwha and Glines Canyon Dams, the Elwha River channel was most likely in a state of dynamic equilibrium where there was no long-term trend of sediment erosion or deposition along the river channel or flood plains. However, this natural equilibrium was disrupted by the construction of the dams in the early 1900's. Today, the reservoirs trap all of the coarse sediment load and about 70 percent of the fine sediment load from the upstream watershed. The reservoir sedimentation, and the resulting reduction in sediment supply to the downstream river channel, has resulted in the erosion and armoring of the riverbed material, increased sinuosity, decreased slope, and significant reductions in suspended sediment concentration and turbidity.

Removal of the two dams and the erosion and downstream transport of trapped reservoir sediments would result in sediment deposition along the downstream river channel, decreased sinuosity, increased slope, and significant increases in suspended sediment concentrations and turbidity. The increases in suspended sediment concentrations and turbidity would initially be large (relative to the upstream sediment supply), but would reduce with time as more and more of the reservoir sediments are eroded and transported past the former dam sites. Once the sediment erosion process in the former reservoirs is essentially complete, the suspended sediment concentrations and turbidities of the upstream and downstream river channels would essentially be the same. This natural equilibrium condition is expected to occur within three years after dam removal, but the actual duration will depend on the frequency, magnitude, and duration of future flood flows and the growth of vegetation in the former reservoir area as outlined in the re-vegetation plan being prepared by the National Park Service.

Monitoring and Assessment

The question has been posed as to when reservoir sediments will no longer have a significant affect on the water quality in the downstream river channel (i.e., the downstream sediment concentrations and turbidities will match the natural conditions upstream from the reservoirs). The determination of when natural suspended sediment concentrations and turbidities are achieved, downstream from the dams, would be based on the results of monitoring data from the river flow (upstream and downstream from the dams), monitoring data from former reservoir areas, and from the results of a terrace bank stability assessment of the former reservoir areas.

A determination that natural conditions have been achieved for suspended sediment concentration and turbidity would be based on the following three conditions:

Condition 1: Stable Relationship between Upstream and Downstream Suspended Sediment Concentrations or Turbidities

Natural conditions will have been achieved when the numerical differences in measured suspended sediment concentration or turbidity, between the gaging stations upstream of Lake Mills and downstream from Elwha Dam, have substantially reduced in the years following dam removal. Even though the concentrations and turbidities should be essentially the same upstream and downstream of the dams, the differences in measurements may not be zero because of sediment contributions from tributaries and the inherent error associated with the measurements. However, the differences are expected to substantially reduce and become stable such that natural conditions are achieved when there is no significant trend in these differences over the most recent winter flood season from November 1st through the end of February. Even if natural landslides were to occur in the upstream watershed, the suspended sediment concentrations and turbidities upstream and downstream from the dams should be essentially be the same.

Use of Monitoring Data:

Continuous measurements of suspended sediment concentration and turbidity are planned at the gaging stations upstream of Lake Mills (to measure natural sediment load) and downstream from Elwha Dam (to show addition of any sediment from Lake Mills and Lake Aldwell). Downstream from Elwha Dam, the stream gage measurements of suspended sediment concentration and turbidity would either be obtained from river flow near the new surface diversion structure or from the river flows that are diverted to the treatment plant.

The continuous measurement of suspended sediment concentration is preferred over the continuous measurement of turbidity because concentration is based on the mass movement of sediment. Turbidity is based on the amount of light penetration through the river flow. However, the continuous measurement of suspended sediment concentration is somewhat experimental and may not always work. Instruments to continuously measure turbidity have been available for years, but during peak sediment concentrations, the river turbidity could exceed the instrument capability. Either type of instrument may be subject of temporary equipment failures. Therefore, the continuous measurement of both suspended sediment concentration and turbidity will be attempted, so that one method can serve as a backup to the other.

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If there were no tributary additions of water and sediment between the gaging stations and there were no measurement error, then the measured differences in concentration and turbidity between gaging stations would all eventually be near zero at some point following dam removal. However, measurement error and sediment inputs from tributaries would likely mean that there is some random difference and some long-term difference in suspended sediment concentration and turbidity. Because the nature of this difference is difficult to predict, any one (or possibly all) of the following three methods would be used to test for a stable trend and a determination of when a natural condition has been achieved for the downstream river channel. The method chosen would depend on a combination of the availability of data at each gage, the duration, frequency, and magnitude of high flows, the impact of measurement error, and the addition of tributary inputs to the downstream sediment load.

1. **Weekly average values above a threshold:** For each of the two gaging stations, compute the weekly average concentration or turbidity for all values above a threshold of 100 mg/l or 10 NTU's. The threshold of 100 mg/l or 10 NTU's is chosen because concentrations or turbidity below this level do not result in any significant water quality issues. If no values within a given week were above the threshold, then the data from that week would indicate that there was no significant sediment erosion from the reservoir areas. If data are available (above 100 mg/l or 10 NTU's) to compute the

weekly average, then the percent difference in concentration or turbidity would be computed at each downstream gage relative to the weekly average for the gaging station above Lake Mills. The percent difference values for each week would then be plotted versus time and the data would be tested to determine if a significant trend still exists or if the relative differences have become stable.

2. **Weekly Maximum Values:** For each of the two gaging stations, determine the weekly maximum concentration or turbidity that is above a threshold of 100 mg/l or 10 NTU's. If no values within a given week were above the threshold, then data from that week would indicate that there was no significant sediment erosion from the reservoir areas. If data are available (above 100 mg/l or 10 NTU's) to compute the weekly maximum, then the percent difference in maximum concentration or turbidity would be computed at each downstream gage relative to the weekly maximum for the gaging station above Lake Mills. The percent difference values for each week would then be plotted versus time and the data would be tested to determine if a significant trend still exists or if the relative differences have become stable.

3. **Weekly Sediment Load:** For each of the two gaging stations, determine the weekly suspended sediment load. For the gage downstream from Elwha Dam, compute the percent difference in the weekly suspended sediment load relative to the weekly suspended sediment load for the gaging station above Lake Mills. The percent difference values for each week would then be plotted versus time and the data would be tested to determine if a significant trend still exists or if the relative differences have become stable.

Because of the potential for equipment failures, the continuous measurement of suspended sediment concentration or turbidity is subject to data gaps. When data gaps occur, the average weekly differences in concentration and turbidity would have to be computed from common time periods where data exist at the two gaging stations. There will also be some lag time between gaging stations that will need to be accounted for. This lag time will tend to decrease with increases in river flow and will have to be determined from field data.

Condition 2: No Significant Change in Reservoir Sediment Volume

After the dam removals, the remaining upstream reservoir sediment will be surveyed on a semi-annual basis to estimate the amount of reservoir sediment erosion. These semi-annual surveys would document the alignment and top elevation of sediment terraces (including bank slope) that border the active river channels and floodplain that have developed eroded through the reservoir sediments. These surveys would be conducted by a crew of three surveyors over a two-day period for each former reservoir.

Condition 2 would be met when the net erosion of reservoir sediments since the last semi-annual measurement in the former Lake Mills and Aldwell is insignificant (less than 5 percent) relative to the long-term average annual sediment load of the Elwha River. The long-term average annual sediment load is estimated at 250,000 yd^3, based on the average annual volume of reservoir sedimentation in Lake Mills for the period 1927 to 1994.

Use of Monitoring Data:

The alignment and elevation of the reservoir sediment terrace banks would be surveyed on a semiannual basis (during the spring and fall) to measure the volume and rate of reservoir sediment erosion. The volume and rate of the reservoir sediment erosion would then be compared with the average-annual sediment transport rate to determine if significant portions of the reservoir sediment were still eroding.

Condition 3: Hydrologic and Geomorphic Evidence of Stabilized Reservoir Sediments

If a significant flood peak occurs within a few years following dam removal, the reservoir sediment could be effectively reworked and transported downstream. If a significant flood peak does not occur, a larger volume of reservoir sediment may remain in the former reservoir area, but in a potentially unstable condition. The re-growth of vegetation may improve the sediment stability, but additional sediment is still expected to erode during a larger flood peak. Condition 3 would be met when the remaining reservoir sediment terrace banks are determined to have attained a level of geomorphic stability comparable to the reference reach at Krause Bottom (Geyser Valley). The Krause Bottom reference reach is upstream of Lake Mills, has an active channel and flood-plain width similar to the future channel and flood plain in the Lake Mills area, and has not been impacted by dam construction.

***Geomorphic Reach Assessment*:**

A geomorphic assessment would be conducted in the former reservoir areas (in conjunction with the semiannual surveys) and the Krause Bottom reference reach. The objective of the geomorphic assessment would be to determine how the reservoir sediment terraces would likely respond to future floods relative to the Krause Bottom reach. Such a determination would be based on criteria including, but not limited to, active river channel and flood plain widths, alignment and planform of the river channel, growth of vegetation, terrace bank slope, and sediment particle size. The riparian forest along the Krause Bottom reach would be more mature and the terrace banks would be likely more stable than the sediment terraces of the former reservoir areas, which will have younger vegetation. However, the assessment of the Krause Bottom reach would provide a good indication of what geomorphic characteristics the former reservoir areas need to either achieve or be trending towards in order to achieve dynamic equilibrium and not pose a risk for significant erosion that could result in elevated sediment concentrations and turbidities in the downstream river channel. The geomorphic reach assessment would be documented in a written report prepared by a licensed engineer or geologist.